BIOSTRATIGRAPHY OF THE UPPER CRETACEOUS AUSTIN GROUP, TRAVIS COUNTY, TEXAS

A Thesis

by

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Submitted to the Graduate College of
Texas A & M University
in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

December 1982

Major Subject: Geology

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December 1982

ABSTRACT

Biostratigraphy of the Upper Cretaceous
Austin Group, Travis County, Texas (December, 1982)
William Maurice Harris, Jr., B.S. Baylor University
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Work within the Austin Group in Travis County is complicated by the dissection of the outcrop area by the Balcones fault zone and the presence of rapid thinning of units into south Travis County. In order to attempt detailed work within the Austin Group the knowledge of stratigraphic position is essential. This knowledge of position is almost impossible if based solely on lithologic data because of the similarity of lithology between some of the formations.

The primary objective of this study is to provide a biostratigraphic zonation of the Austin Group within Travis County. Based on collection of fossils and a consideration of the lithologic units within the Austin Group, five biozones were established. They are 1) Inoceramus subquadratus zone, 2) Pycnodonte aucella - Pycnodonte wratheri zone, 3) Trigonia aliformis zone, 4) Exogyra tigrina zone, and 5) Alectryonia falcata - Hamulus squamosus zone. In addition to these biozones, sixteen biohorizons are listed to allow more detailed work within the formations.

Previous zonations of the Austin Group established outside of Travis County are not useful within Travis County. Stephenson's (1937) zonation, based on correlation over a broad area, is not useful in detailed stratigraphic work. Young and Marks' (1952) zonation,

based on collection in Williamson County to the north, does not work because some of their species are not found within the outcrops of Travis County.

The secondary objective of this study is to determine the depositional environment of the Austin Group. The Austin Group within Travis County was deposited on a shallow water ramp between the San Marcos Arch, nearby to the south, and the East Texas Embayment to the north. Tectonic movement, which started at the beginning of the deposition of the Upper Austin Group, affected the paleobathymetry on the ramp. This tectonic activity included the formation of a volcano located in southeast Travis County near the community of Pilot Knob. The movement of the sea floor increased the steepness of the ramp and was responsible for 1) a marked thinning of the lithologic units from north to south and 2) a compression of the depositional facies along the ramp.

ACKNOWLEDGMENTS

Appreciation is extended to Dr. R. J. Stanton, Department of Geology, Texas A & M University, for his aid and guidance in the preparation of this thesis. Thanks are also extended to Dr. W. M. Ahr, Department of Geology, and Dr. E. N. Powell, Department of Oceanography, Texas A & M University, for their expertise in the analysis of field data and aid in preparation of this thesis. Special thanks go to Nancy Turner, fellow co-worker on the Austin Chalk, for her moral support and input during the preparation of this study. Deep gratitude is owed my field assistants; John Hopewell, Mike Whelan, Darrell Oldham, and the Texas A & M Paleontology Club, for aiding me during the field portion of this study. Thanks are extended to other members of the Geology faculty and staff of the Geology Department of Texas A & M University, and to fellow graduate students for their contribution of time and thought. Very special thanks are extended to my family and relatives for their support, both emotional and financial, during the completion of this study.

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INTRODUCTION

The Austin Chalk in Travis County is a prominent lithologic unit. The Austin is exposed within the fault blocks of the Balcones Fault Zone. This faulting complicates correlation within the individual formations of the Austin Group.

Taff (1892) noted that the Austin Chalk, originally of formation status, could be divided into four distinctive (mapable?) units. This finding resulted in the elevation of the Austin to group status. Durham (1957) divided the Austin Group of Central Texas into six formations (fig. 1). These formations are, from oldest to youngest, Atco, Vinson, Jonah, Dessau, Burditt, and Big House. Deposition of the Atco and part of the Vinson occurred during the Coniacian stage and deposition of the remaining formations was during the Santonian (Bose, 1927).

Deposition of the Austin Chalk in Travis County was controlled by fluctuations of the sea floor. The rock record is incomplete in some areas as attested to by the different thicknesses and unconformity surfaces found throughout (Durham, 1957). These facts, when complicated by rapid facies changes, make difficult the efforts to establish a biostratigraphic zonation that could be used throughout Central Texas. Macrofauna, being the most controlled by micro-environmental variables, are the most difficult biota with which to establish a zonation. The zonations previously available are old and

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This thesis follows the style of the U.S. Geological Survey Prof. Paper #791, Oligocene Molluscan Biostratigraphy and Paleontology of the Lower Part of the Type Temblor Formation, California by W. O. Addicott, (1973).

<table>
<tr><th>System</th><th>Stage</th><th>Group</th><th>Formation</th></tr>
<tr><td rowspan="9">CRETACEOUS</td><td>CAMPAN-IAN</td><td>TAYLOR</td><td>Taylor Shale</td></tr>
<tr><td rowspan="4">SANTONIAN</td><td rowspan="6">AUSTIN</td><td>Big House - Pflugerville</td></tr>
<tr><td>Burditt</td></tr>
<tr><td>Dessau</td></tr>
<tr><td>Jonah</td></tr>
<tr><td rowspan="2">CONIACIAN</td><td>Vinson</td></tr>
<tr><td>Atco</td></tr>
<tr><td rowspan="2">TURONIAN</td><td rowspan="2">EAGLE FORD</td><td>South Bosque</td></tr>
<tr><td>Lake Waco</td></tr>
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Fig 1. Stratigraphic section of the Austin Group, Travis Co., Texas.

difficult to apply. Stephenson (1937) based his zonation on a regional study of the Austin Chalk throughout Northern Mexico, Texas, Arkansas, and Alabama. This zonation is difficult to use in detailed work within Travis County. Young and Marks (1952) based their zonation of the Austin on outcrops within Williamson County, north of Travis. Because out-of-date stratigraphic information had been used, the validity of their zonation is questionable (Durham, 1957, p. 31).

Purpose

The main objective of this thesis is to provide a list of the fauna present within the formations of the Austin Group and, based on these data, attempt to provide a zonation based on the occurrence or absence of common organisms. The zonation will be useful in later studies of the Austin Group, both in Travis and in adjoining counties.

The secondary objective of this thesis is to determine the paleoecological setting of the Austin Group at the outcrop localities. The depositional setting of the Austin Group has been a question among most persons working with the lithologic evidence (Taylor, 1982). Through a synthesis of faunal, lithologic, regional, and facies data, an analysis of the depositional setting is made.

Location

Three outcrops in Travis County are used in preparing the biostratigraphic listing. To establish a zonation the outcrops must provide as complete a section as possible. In order to make a paleoecological analysis of the depositions of the Austin, the outcrops must be within as small an area as possible. Within a carbonate depositional setting, the environment may change significantly over very short distances, so proximity of localities is important. The three outcrops used in the faunal zonation have three important attributes. First, to provide a complete zonation of the Austin Group, they possess as continuous a section as possible. Second, they have been recognized by other authors as being important localities from which to observe each formation. These outcrops have been used in publications (Pessagno, 1969; Beikirch and Feldman, 1980), dissertations (Durham, 1957), and professional level fieldtrips (Ahr, 1979). Finally, they are easily accessible for others to use. (See Appendix III.)

The three outcrops utilized (fig. 2) are 1) the creek bed under the Missouri Pacific Railroad bridge between Oltorf and Mary Street, (fig. 3); 2) on Vinson Creek on the upstream side of the Bluff Springs Road bridge, (fig. 4); and 3) on Little Walnut Creek on the upstream side of Texas 290, (fig. 5). The oldest formation, the Atco, is exposed in the creek bed and to the sides of the MOPAC Railroad tracks in southeast Travis County. Thirty-four feet of the Atco Formation are exposed here but neither the upper nor lower contacts are present. The section at this outcrop is representative of the predominant Atco lithologies found in central Texas. (See Appendix III.)

The Vinson and Jonah Formations are exposed on Vinson Creek, southwest of the Austin city limits. This section is the type locality for the Vinson Formation. The upper fifty-five feet of the Vinson is exposed at this location. The Vinson is overlain by the

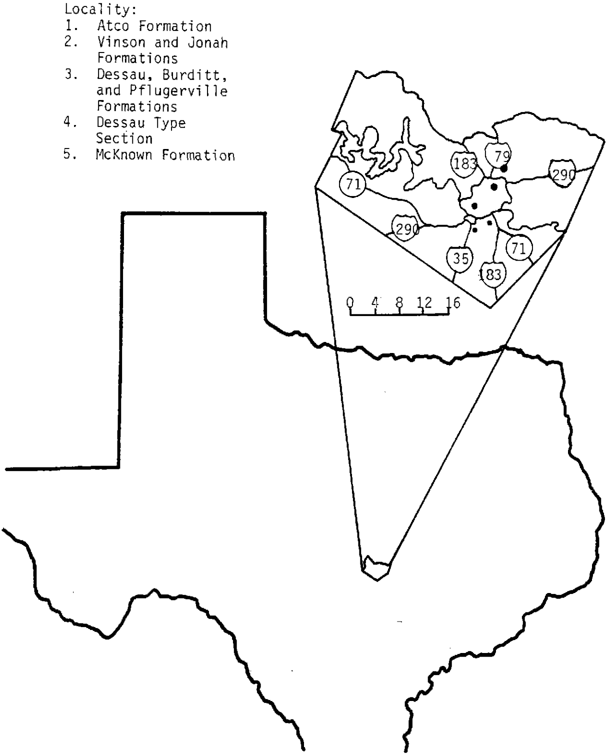

Figure 2. Index map with the location of the outcrops used in this study.

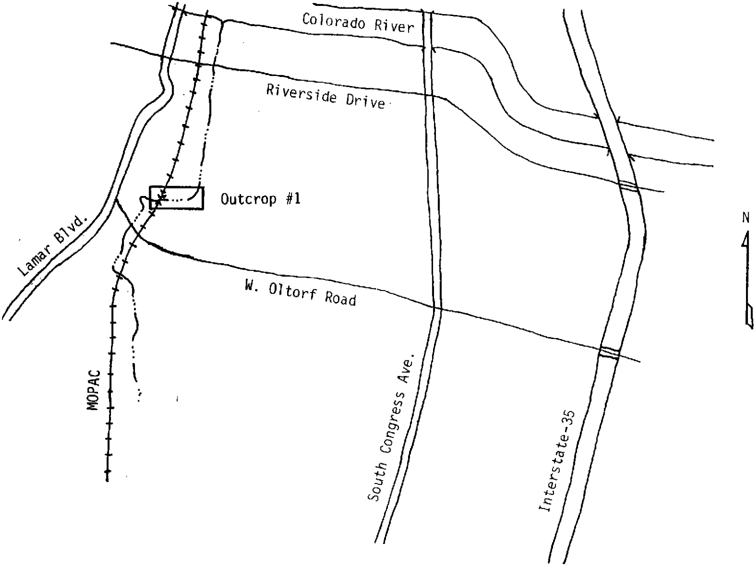

Figure 3. Map of the Atco locality.

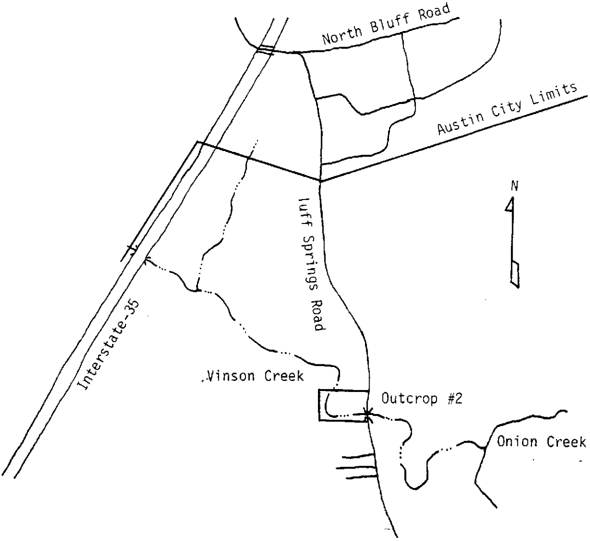

Figure 4. Map of the Vinson Creek locality.

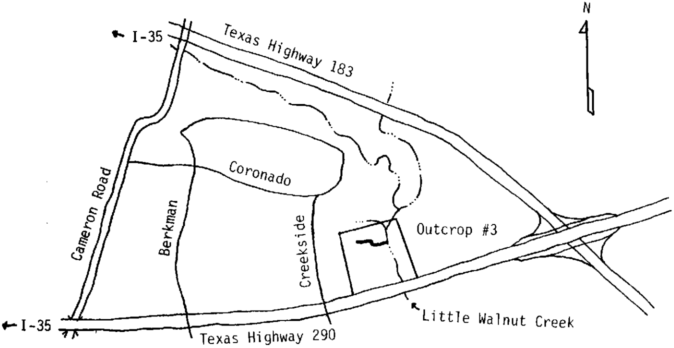

Figure 5. Map of the Little Walnut Creek locality.

twenty-four foot thick Jonah Formation. The lower portion of the Dessau is present as the uppermost unit of this section (Durham, 1957). (See Appendix II.)

The upper Austin group is exposed on Little Walnut Creek, one-eighth mile upstream from the Highway 290 bridge in the eastern Austin city limits. At this outcrop the upper 18 feet of the Dessau, the 26 foot thick Burditt Formation, and the 30 foot thick Pflugerville Formation may be found (see Appendix II).

Two additional outcrops are used to complete the stratigraphic section. The type section for the Dessau Formation, three-quarters of a mile downstream from the Austin-Dessau Road bridge on Walnut Creek, (fig. 6) overlaps and ties together the Vinson Creek and Little Walnut Creek sections. Construction of a land development has begun in the area of this section and has somewhat altered some of the outcrop characteristics (i.e., river level). The final outcrop, at McKinney Falls State Park, provides a description of the McKnown Formation (fig. 7). The McKnown is the shallow water volcanic pyroclastic facies of the Dessau near the Pilot Knob Volcano (see Appendix II). Whole body fossils are rare to absent at this section, but the stratigraphic sections exposed aid in the interpretation of the paleoecological setting for the upper Austin Group.

Methods

Field work, consisting of initial reconnaissance and collection of the outcrops, took place between September, 1981 and March, 1982. The locations were studied in order to determine sampling methods and

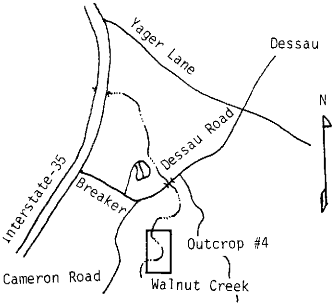

Figure 6. Map of the Dessau type locality.

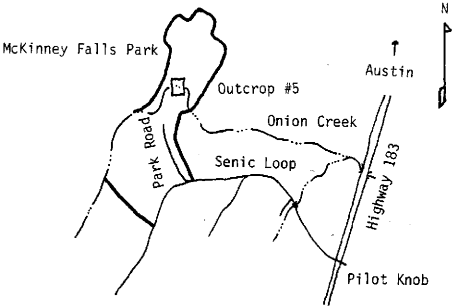

Figure 7. Map of the McKinney Falls locality.

lithologic descriptions. The outcrop characteristics at each section, (slope and weathering), required that different collection procedures be used at each section. The lithologic units were sampled to determine the lithologic information necessary to construct the stratigraphic sections. The rock samples were slabbed and observed under a binocular microscope. The description of each sample/unit is included in Appendix II.

The fossil collection technique had to be adjusted to the characteristics of each outcrop. The extremely low density of body fossils at the Atco section required a thorough observation of all possible outcrop area. The only specimens found were, Inoceramus and a rudist, impossible to remove without breaking. Pictures and notation of the in place shells were made. The Vinson Creek outcrop, with its steep slope, has very few surface fossils, and diagenesis has degraded most of the fossils that were found. A unit-by-unit collection was required. The third section, at Little Walnut Creek, is optimum for the collection of samples. The high density of fossils at this locality allows for the collection of numerous samples. The high clay content weathers to a low slope, allowing whole shells to be exposed in place in great abundance.

The macrofauna were cleaned and identified to the lowest taxonomic level possible. Once the fossils were identified they were listed by formation for biostratigraphic purposes. To determine the overall usefulness of the individual fauna, range charts for the complete Austin Group were drafted (see Appendix III). Other lab work included the slabbing and description of the rock samples taken at each outcrop.

Previous Work

Roemer (1852) observed some Austin outcrops in Comal County and, with the use of fossils, properly identified them as being of late Cretaceous age. In 1860, Schumard named this sequence of rocks the Austin limestone; he also indicated that the outcrops of this limestone could be found in Comal, Travis, Grayson, and McLennan Counties. Shumard incorrectly placed the Austin below the Comanche Peak Limestone, and correctly placed it above the Eagle Ford shales.

Hill (1887) correctly placed the Austin limestone, which he called the Dallas limestone, into sequence above the Eagle Ford shales and below the Taylor marls. In 1892, Taff noted that the Austin limestone in Williamson County could be divided into four units based on distinctive lithologies. Adkins, et al, (1933) divided the Austin into two separate units, a lower unit of typical Austin deposits, and an upper unit of marl. The upper unit was to be named the Burditt chalk marl and could be traced from Austin to Waco.

In 1937, Stephenson set Travis County as the place for the type section of the Austin chalk. His type section was composed of 420 feet of interbedded hard chalk, soft chalk, and chalky marl. Durham (1955) divided the Austin chalk in Central Texas into two basic divisions. The lower unit was comprised of the Atco, Vinson, and Jonah Formations. The upper unit was comprised of the Dessau, Burditt, and Big House Formations. McNulty (1955) collected foraminifers from the upper chalk in Dallas and Travis Counties and determined that they were not time equivalent. Durham (1957) correlated the upper Austin with the lower Taylor marl of Dallas County. McNulty (1976) later studied the age discrepancy in more detail and determined that the lower two-thirds of the Pflugerville (currently used in place of Big House) Formation was of Austinian age and the upper third was of lower Taylorian age.

Paleontological studies of the Austin Group could not begin in earnest until a proper stratigraphic framework was established. Early studies were concerned with the determination of the age of the Austin limestone. Roemer (1852) collected enough fossils from the Austin limestone to determine that it was of late Cretaceous age. Because of the unavailability of a stratigraphic framework from which to continue, Roemer was unable to further refine his age determination. In his study of *Exogyra*, Bose (1927) was able to refine the age determination of the lower and middle Austin to Coniacian and the upper Austin to Santonian.

Stephenson (1937) divided the Austin Chalk into five biozones based on bivalves. These zones (fig. 8), from bottom to top, are (1 *Inoceramus undulatoplicatus*, 2) *Gryphaea wratheri*, 3) *Exogyra tigrina*, 4) *Ostrea centerensis*, and 5) *Ostrea traviscana*. Stephenson's zonation, however, covers only the middle and upper portions of the Austin Group because of the presence of multiple unconformities within the Group. Young and Marks (1952) worked in Williamson County to be able to use an entire Austin sequence. They recognized six zones (fig. 8 that encompass the whole group. The zones, from bottom to

	Stephenson, 1937	Young and Marks, 1952	Pessagno, 1969
Pflugervill	Ostrea traviscana	Ostrea traviscana	Globotruncana bulloides
Burditt	Ostrea centerensis	Ostrea centerensis	
Dessau	Exogyra tigrina	Exogyra laeviscula	
	Gryphaea wratheri	Gryphaea aucella	
Vinson		Texanites internodosus	Marginotruncana renzi
Jonah	Inoceramus undulato-plicatus	Inoceramus undulato-plicatus	
Atco	None named	Inoceramus subquadratus	

Figure 8. Comparison of the zonations of the Austin Chalk by Stephenson, Young and Marks, and Pessagno. No lithologic thickness inferred (adapted from Young, 1963).

top, are 1) _Inoceramus subquadratus_, 2) _Inoceramus undulatoplicatus_, 3) _Texanites internodosus_, 4) _Gryphaea aucella_, 5) _Exogyra laeviscula_, and 6) _Ostrea centerensis_.

Durham studied the outcrops of the Austin Group throughout Texas and northern Mexico and concluded that Stephenson's zonation was not sufficient to use in detailed work on the Austin because he had relied too heavily on fossil evidence and not enough on stratigraphic information to have completed a useful zonation; also he knew neither the lateral extent of the fossils upon which he based his zonation nor how complete the section was with which he worked. Similarly, Bell (1950) also stated that any biological zonation of the Austin only could be done once a proper stratigraphic framework had been established. Young and Marks (1952) compiled their zonation in Williamson County with a "more complete" section. Durham found that miscorrelation was still possible because of the difference in facies distribution over long lateral distances.

Gimbrede (1961) studied the benthonic and planktonic foraminifera of the Austin Group and established a foraminiferal zonation. Hazel and Paulson (1964) studied the ostracoda of the Austin Group in Travis, Dallas, and Fannin Counties in order to correlate the outcrops in these areas. They found 42 species, 13 of which were new. Four of the 42 species proved to be of value in extending the usefulness of macrofaunal zonations across facies boundaries.

Pessagno (1969) established Upper Cretaceous microfaunal assemblage zones for Mexico, Texas, and Arkansas (fig. 8). These assemblage zones are less narrowly defined than the biozones of

Stephenson or Young and Marks, being defined on the basis of species assemblages and not on the basis of any one species. The lower Austin is in his Marginotruncana renzi Assemblage zone and the middle to upper Austin is in his Globotruncana bulloides Assemblage zone.

Recently, Beikirch and Feldman (1980) described several decapod crustaceans from the Pflugerville Formation in Travis County at the Little Walnut Creek locality.

As the Austin Chalk has become better understood, the early zonations have become less useful. The regional depositional setting indicates that lateral facies changes may be as responsible for the distribution of the fauna as the time factor is. In Travis County facies changes occur over short distances and the application of regional zonation techniques are not adequate. In addition to faunal range information, zonation of the Austin Group must include consideration of facies, lithology, and the regional depositional setting. The paleoecologic setting may be as important in this area as stratigraphic distribution has been in past zonations.

Included in this thesis are a faunal listing, faunal range charts, stratigraphy, paleoecologic analysis, and a biostratigraphic zonation for the Austin Group in Travis County, Texas.

STRATIGRAPHY

A major unconformity at the Jonah-Dessau contact divides the Austin Group in Central Texas into two parts (fig. 1, p.). The upper division, the Dessau, Burditt, and Pflugerville Formations, is composed of chalk and marl. The lower division is composed of chalk and nodular skeletal packstone (Durham, 1957). The nodular characteristic of the latter units is typical of other Cretaceous rocks of Central Texas.

Lower Austin

The lower part of the Austin Group in Travis County is divided into the Atco, Vinson, and Jonah Formations (fig. 9). The type locality for the Atco formation is at the Universal Atlas Cement Company in McLennan County, Texas. At the type locality the Atco is 240 feet thick and is composed of white, resistant beds of chalk separated by thin beds of blue gray marl. The Atco thins to 40 feet in the San Marcos area (Seewald, 1959, p. 14-15). The lower contact with the Eagle Ford Shale was recognized by Dumble (1892) as being disconformable, as evidenced by borings and reworking of Eagle Ford fossils into the basal Atco. In Travis County, the lower part of the formation and the disconformable lower contact are exposed in only a few localities, being predominantly hidden in the fault blocks of the Balcones Fault zone. The Atco is seventy to ninety-seven feet thick in Travis County (Durham, 1957), and is composed of interbedded white massive, resistant beds of chalk separated by beds of heavily bioturbated blue gray marl. Thirty-four feet of the Atco Formation is

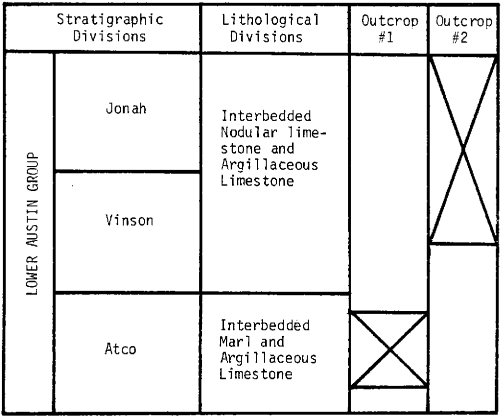

Figure 9. Lower Austin Group. Relationship between the localities and section coverage.

present at the MOPAC locality. The lower twenty and upper sixteen feet of the Atco is missing at the MOPAC locality. The Atco is of consistent lithology and the thirty-four feet studied is representative of the total Atco Formation. The contact between the Atco formation and the overlying Vinson Formation is gradational (Durham, 1957).

The type locality for the Vinson Formation is on Vinson Creek, one-half mile north of Onion Creek on Bluff Springs Road in southeast Travis County. The Vinson Formation ranges from 220 feet thick in Dallas County to 37 feet thick in Bexar County (ibid). At the type locality, used in this study, the upper 55 feet of the Vinson is exposed, the lower half and the basal contact are not present (Miller, 1978). The Vinson Formation is composed of medium bedded, nodular, skeletal packstone interbedded with thin seams of blue gray marl. The contact between the Vinson and Jonah Formations at Vinson Creek is conformable.

The type locality for the Jonah Formation is on the San Gabriel River at the Jonah-Hutto roadcrossing in Williamson County. At the type locality, the upper 35 feet of the Jonah is exposed; the lower 50 feet is exposed two-thirds of a mile upstream. The Jonah Formation ranges from 120 feet thick in Bell County to 25 feet thick in Travis County. The Jonah Formation from the type section down into Travis County is composed of slightly glauconitic, fossiliferous limestone beds separated by thin beds of marl (Durham, 1957). The Jonah Formation at Vinson Creek is 25 feet thick and the limestone beds are skeletal packstones. The thinning of the Jonah Formation is caused by the positive influence of the San Marcos Arch during deposition.

The contact between the Jonah Formation and the Dessau Formation is disconformable. The disconformity surface separates the lower Austin Group from the rocks of the upper Austin Group. The lower Austin Group changes from a quiet water deposit at the base to a higher energy, shallower water deposit at the top. This progression of energy environments culminated in the formation of the unconformity between the lower and upper divisions of the Austin Group.

Upper Austin

The type locality for the Dessau Formation is on Big Walnut Creek, three quarters of a mile downstream from the Austin-Dessau road bridge (fig. 10). The Dessau attains a thickness of 200 feet in Bell County and thins to 85 feet in Travis County (Ahr, 1979). The entire Dessau is exposed at the type section. The lower ten feet is composed of fragmental packstone with a high concentration of glauconite. A second disconformity surface occurs approximately three feet above the base of the Dessau. The lower ten feet of fragmental packstone is overlain by chalk. Three prominent oyster biostromes occur in the upper 35 to 75 feet of the Dessau (Durham, 1957). At the Little Walnut Creek section the upper 32 feet is exposed. The Dessau at this section is a wackestone/mudstone with two prominent *Exogyra* biostromes. The lower biostrome is three feet above the base of the section and composed up of *Exogyra tigrina*. The upper biostrome is 18 feet above the base of the section and is composed of *Exogyra laeviscula*. The contact between the Dessau and Burditt Formations is disconformable.

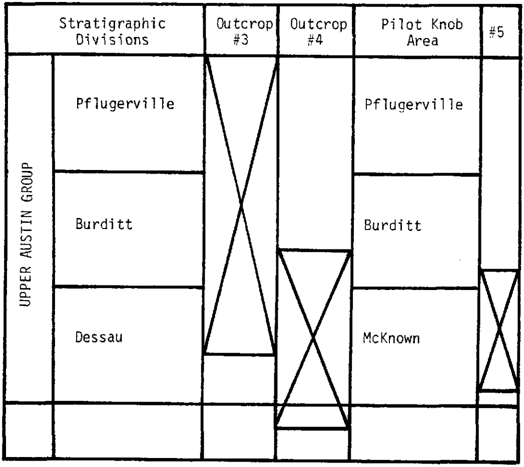

Figure 10. Upper Austin Group. Relationship between the localities and section coverage (including the Dessau type section and the Pilot Knob section).

The type locality for the Burditt Formation is on Little Walnut Creek at the abandoned Cameron Road crossing. The thickness of the Burditt ranges from 30 feet in Bell County to zero feet near Pilot Knob in southeast Travis County. The Burditt Formation thickens from zero feet near Pilot Knob in southeast Travis County to 24 feet in northern Travis County. The basal Burditt near Pilot Knob contains rip-up clasts of volcanic material from the McKnown facies of the Dessau Formation (Ahr, 1979). At the Little Walnut Creek locality the basal Burditt is a nodular chalk. The upper portion of the Burditt formation at the Little Walnut Creek section is composed of marly limestone with two prominent, but thin, coquinoid beds near the top (Durham, 1957). The contact between the Burditt Formation and the overlying Pflugerville Formation is gradational.

The type locality for the Pflugerville, or Big House, Formation is on the San Gabriel River across from the mouth of Big House Branch Creek. The Pflugerville Formation is approximately forty feet thick at this locality, but never attains so great a thickness in Travis County, ranging from almost zero feet in the southeast to only 30 feet at the Little Walnut Creek locality. It is a transitional formation between the Austin and Taylor Groups. This unit at Little Walnut Creek is predominantly chalk at the base with a transition to a marly chalk at the top, the latter typical of the deposits of the Taylor Group (Miller, 1978). The upper contact with the Taylor is disconformable and, because of the similar lithologies, is difficult to discern without the aid of microfossils (McNulty, 1976). At the Little Walnut Creek locality the boundary between the Austin and

Taylor Groups is covered and is marked by a change in the fossil composition.

During the deposition of the upper Austin Group, volcanic activity, as evidenced by the Pilot Knob volcano, controlled deposition in southeast Travis County. The volcanic activity primarily occurred during the deposition of the Dessau Formation. This unit, present in the Pilot Knob area, is the McKnown or "pyroclastic" Formation (Ahr, 1979) (fig. 11). This unit is composed of highly altered ash flows and volcanic tuffs that ring the basaltic volcanic core (Miller, 1978). The basal contact is characterized by undulation caused by 1) differential loading of the volcanic material on the soft carbonate deposits or 2) the creation of channels by the movement of material away from the volcano. The overlying limestones contain some reworked volcanic clasts and are predominantly skeletal grainstones.

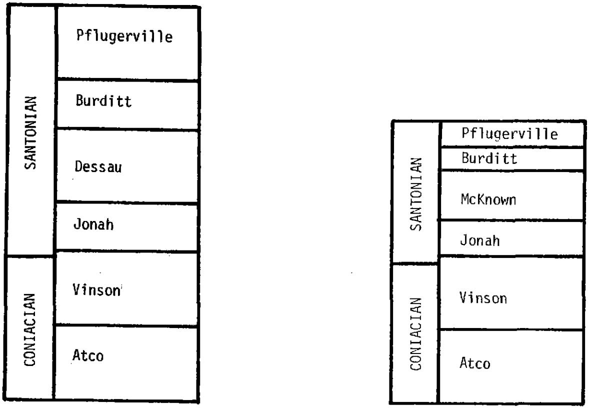

Figure 11. Comparison of the thickness and sequence of the Austin Group in North Travis County and near the Pilot Knob volcano. Note the Dessau / McKnown correlation.

PALEONTOLOGY

Analysis of Data

Sampling strategy depended upon lithology. Outcrops on steep slopes and rocks with high clay content provided abundant samples and data, whereas outcrops on high slopes and low clay content provided less abundant samples and required a more intense collection procedure. The fossils were identified in the laboratory using Adkins (1928), Stephenson (1937), Young and Marks (1952), and others for initial indentification, with later confirmation by comparison with the plates of the holotype (i.e. Roemer, 1852 and Agassiz, 1843) where possible. The species' names are listed in Appendix III. Ninety-two taxa were identified, sixty-two to the species level. The specimens that were fragmented were identified as completely as possible and are indicated by the notation "sp. aff." in the name between the genus and species name. Many specimens, especially the Inoceramus fragments, were identifiable only to the genus level and are listed as Genus sp.

The fauna is predominantly molluscan (70%) in terms of the number of species (bivalves being 51% of all species listed) and also in number of individuals. Other invertebrates, excluding trace fossils, comprised 17% of the species. The remaining percentage is made up of shark species and four types of burrows. Relative abundances of taxonomic groups are listed in Table 1. This high percentage of bivalves is characteristic of Cretaceous rocks of Central Texas. The abundance of the rudistid bivalves in the Edwards Formation is another example of bivalve dominance. Other formations in which bivalves are dominant are the Glen Rose and Comanche Peak (Harris, 1980). Possible explanations are 1) preservational differences caused by shell composition or

Table 1. Percentage composition by taxonomic type.

Pelecypoda	51.6%
Gastropoda	12.9%
Cephalopoda	6.4%
Shark Teeth	6.4%
Bryozoa	4.8%
Annelida	4.8%
Trace Fossils	3.2%
Echinodermata	3.2%
Brachiopoda	1.6%
Porifera	1.6%
Coelenterata	1.6%
Mammal	1.6%
	99.5%

resistance to breakage, or 2) molluscan domination of the bottom community as is now in existence in many areas along the northwest coast of North America (Valentine, 1973).

The taxa, subdivided on the basis of feeding type (Dodd & Stanton, 1981), consists of filter feeders 64.5%, deposit feeders 6.4%, and carnivores 29%. The percentage abundance of deposit feeders is even greater in terms of numerical abundance. Benthic taxa are predominantly epifaunal: 80% were epifaunal and 20%, infaunal.

A comparison of the diversity and richness of each formation is provided in Table 2. A more detailed discussion is provided later in this section. As used here, a high diversity is 25 or more taxa, medium diversity is 12 to 24 taxa, and low diversity is less than 11 taxa present. High richness is 30 or more specimens per square meter, medium richness is 11 to 29 specimens per square meter, and low richness is 10 or fewer specimens per square meter.

Table 2. Formation diversity and richness.

Formation	# Species	Diversity	Richness
Pflugerville	20	Medium	Medium
Burditt	32	High	High
Dessau	18	Medium	Medium
Jonah	16	Medium	Medium
Vinson	28	High	Medium
Atco	3	Low	High

When composition of species is compared to lithology, marls and chalks in this case, several relationships are evident. The marls, which are higher in clay content, have greater richness and bioturbation but lower species diversity and molluscan content in general. Chalk beds, with a lower clay content, have a higher diversity and richness. The trace fossils found in the chalks appear to be parallel to the bedding planes whereas the trace fossils in the marls cut across bedding planes. The differences in trace fossils could represent differences in deposition. The chalks have a high molluscan diversity and trace fossil richness. The bivalve fragments are abundant enough in some of th chalk units to be the primary lithologic component (= 50%) of the rock.

Faunal Analysis: Lower Austin

Diversity in the Atco Formation is low; richness is high (Table 3). The bivalves comprise approximately two-thirds of the number of taxa present, but is less than 30% of the individuals. Burrowing is greater in marl units than in limestone units. Although inoceramids

Table 3. Species found in the Atco Formation

Pelecypoda	
5.	Durania austinensis Roemer
+13.	Inoceramus subquadratus Schluter
14.	I. sp. af. subquadratus
15.	I. sp.
16.	I. sp., thick shell
Trace Fossils	
+94.	Zoophycos

Note: + denotes species found only in this formation.

are present throughout the Austin Group, the bivalve Inoceramus subquadratus Schluter is found only in this unit. One specimen of the rudist Durania austinensis Roemer was found in life position in the upper portion of this unit (see Appendix IV). Zoophycos is present only in this unit.

The Vinson formation contains 28 species, 16 of which are bivalves (Table 4). The most abundant species is the bivalve Pycnodonte wratheri Stephenson. This species is very numerous and exists throughout this formation. P. aucella Roemer occurs in conjunction with P. wratheri in the Vinson but occurs sporadically and is not present in great numbers until the middle of the formation (see Appendix IV).

The Vinson has high diversity and medium richness. Small, thin-shelled bivalves comprise a large portion (= 50%) of the lithologic composition in the chalk units.

Table 4. Species found in the Vinson Formation

Pelecypoda

- 3. Anomia micronema Meek
- +10. Inoceramus sp. aff. cripsii Mantell
- 11. I. grandis Conrad
- 12. I. sp. aff. grandis
- 14. I. sp. aff. subquadratus Schluter
- 15. I. sp.
- 16. I. sp., thick shell
- 17. I. sp., thin shell
- 21. Lima sp. aff. reticulata Forbes
- 22. Lima sp.
- 25. Modiola sp. aff. granulo-cancellata Roemer
- 26. Neithea austinensis Kniker
- 27. N. casteeli Kniker
- 28. N. hartmani Kniker
- 33. Ostrea sp.
- 34. Pecten bensoni Kniker
- 35. Pecten sp.
- 36. Pycnodonte aucella Roemer
- +37. P. wratheri Stephenson
- 39. P. sp.
- 40. Spondylus guadalupe Roemer
- 45. Cucullea sp. Shumard
- 47. Volutomorpha sp.

Cephalopoda

- 51. Baculites anceps Lamark
- +53. B. asper Morton
- +54. B. sp. aff. asper
- 56. Texanites internodosus Renz
- +57. T. sp. aff. planus Lasswitz

Gastropoda

- 58. Architectonica sp.
- +61. Nerina sp.

Echinodermata

- +66. Hemiaster texana Roemer
- 67. Spines

Bryozoa

- 71. Aplousina sp. aff. gigantea Conrad

Porifera

- 74. Cliona microtuberum Stephenson

Annelida

- 76. Serpula pervermiformis Wade

Table 4 contd.

Trace Fossils

Thalassinoides

Circular cross-section

84. 1. straight

85. 2. tapering

Oval cross-section

88. 2. arcuate

+89. 3. intersection

Flattened cross-section

90. 1. straight

91. 2. tapering

92. Nodulose burrow

Note: + denotes species found only in this formation.

The Jonah Formation is a medium diversity unit with a medium richness. There are 17 species of which 64% are bivalves (Table 5).

Table 5. Species found in the Jonah Formation

Pelecypoda

3. Anomia micronema Meek
7. *Exogyra ponderosa Roemer
11. Inoceramus grandis Conrad
15. I. sp.
16. I. sp., thick shell
17. I. sp., thin shell
21. Lima sp. aff. reticulata Forbes
27. Neithea casteeli Kniker
28. N. hartmani Kniker
33. Ostrea sp.
36. Pycondonte aucella Roemer
39. P. sp.
40. Spondylus guadalupe Roemer
42. Trigonia sp. aff. aliformis Goldfuss
45. Cucullea sp.
47. Volutomorpha sp.

Cephalopoda

51. Baculites anceps Lamark

+52. B. sp. aff. anceps

Gastropoda

64. Turritella sp.

Table 5 contd.

Brachiopoda

70. Terebratulina guadalupe Romer

Trace Fossils

Thalassinoides

Circular cross-section

84. 1. straight
85. 2. tapering
+86. 3. constriction present

Oval cross-section

87. 1. straight
88. 2. arcuate

Flattened cross-section

90. 1. straight
91. 2. tapering

Note: + denotes species found only in this formation.
* denotes a species which may have fallen from the formation above.

The lower portion of this formation contains numerous burrows and straight cephalopods (Baculites anceps Lamark). Pycnodonte aucella is present throughout this formation but in few numbers (see Appendix IV). Some specimens of the bivalves Exogyra ponderosa Roemer and Trigonia sp. aff. aliformis Golfuss, none found in place or in life position, were found in the uppermost unit of this formation and are considered to have fallen down from the basal Dessau unit at the top of the Vinson Creek section.

Faunal Analysis: Upper Austin

The upper Austin Group occurs above a regional unconformity (Durham, 1957). This boundary coincides with the lower boundary of the Exogyra ponderosa zone of the Atlantic Gulf Coastal Plain (Stephenson, 1923, Plate 8). At this boundary a number of Exogyra first occur including E. laeviscula Roemer and E. tigrina Stephenson. It is also at this boundary that, as it occurs in the Atco Formation, large, whole-shell Inoceramus may be found. The inoceramids, both shells and molds, vary in size from six inches to three feet from the beak to the anterior margin.

The Dessau Formation is a variable unit with decreasing diversity towards the top. The richness varies from low, most common, to high in the Exogyra biostromes. There are 17 species present, 14 of which, or 82%, are bivalves (Table 6). This unit contains the largest

Table 6. Species found in the Dessau Formation

Pelecypoda
1. *Alectryonia falcata Morton
+ 4. Astarte (?) lineolata Roemer
6. Exogyra laeviscula Roemer
8. E. tigrina Stephenson
9. E. sp.
11. Inoceramus grandis Conrad
15. I. sp.
16. I. sp., thick shell
17. I. sp., thin shell
21. *Lima sp. aff. reticulata Forbes
27. Neithea casteeli Kniker
28. N. hartmani Kniker
30. Ostrea centerensis Stephenson
31. O. congesta Conrad
32. *O. plumosa Morton
33. O. sp.
39. Pycnodonte sp.
+41. Trigonia aliformis Goldfuss
42. T. sp. aff. aliformis
+43. T. sp.
45. Cucullea sp.

Echinodermata
67. Spines

Annelida
75. *Hamulus squamousus Gabb
76. Serpula pervermiformis Wade

Table 6 contd.

Trace Fossils
- Thalassinoides
- Circular Cross-section
- 85. 2. tapering

Note: + denotes species present only in this formation.
* denotes a species which may have fallen from the formation above.

Inoceramus molds and body fossils present in the Austin Group, the largest being two feet in width and three feet in length. The most notable feature of this formation is the Exogyra biostromes. These biostromes contain very numerous small Exogyra, most less than two inches in length. The Exogyra appear in different orientations with few specimens articulated. The biostromes, averaging six feet wide and twenty feet long, are somewhat limited in lateral extent and exist sporadically throughout the upper Dessau.

The Burditt Formation contains 43 species or 70% of the species found in the Austin Group. Twenty-two of the species are bivalves. Seventeen of the species are found only in this unit (Table 7). The diversity is high at the base and decreases rapidly upwards but the richness remains high throughout. A nodular lithology very rich in pelecypods and gastropods is six to ninee feet from the base of this formation (see Appendix IV). This unit has abundant shark teeth and a jaw fragment possibly belonging to the mammal Trithecodon. Above the nodular unit two species become important in terms of numbers of individuals. The bivalve Alectryonia falcata Morton and the annelid Hamulus squamosaus Gabb are present in abundance from the top of the nodular unit to the top of the Pflugerville Formation.

Table 7. Species found in the Burditt Formation.

Pelecypoda

1. *Alectryonia falcata* Morton
\+ 2. *Anomia anomiaeformis* Roemer
3. *A. micronema* Roemer
7. *Exogyra ponderosa* Roemer
8. *E. tigrina* Stephenson
9. *E.* sp.
12. *Inoceramus* sp. aff. *grandis* Conrad
15. *I.* sp.
\+18. *Lima crenulicostata* Roemer
19. *L.* sp. aff. *crenulicostata*
21. *L.* sp. aff. *reticulata* Forbes
22. *L.* sp.
\+23. *Linearia* (?) *cancellato-sculpta* Roemer
\+24. *Liopistha* sp. aff. *elegantula* Roemer
26. *Neithea austinensis* Kniker
\+48. *N. boesi* Kniker
27. *N. casteeli* Kniker
28. *N. hartmani* Kniker
29. *N.* sp.
30. *Ostrea centerensis* Stephenson
31. *O. congesta* Conrad
32. *O. plumosa* Morton
34. *Pecten bensoni* Kniker
39. *Pycnodonte* sp.
44. *Cucullea* sp. aff. *millestriata* Shumard
45. *Cucullea* sp.
46. *Lineria* sp.
47. *Voultomorpha* sp.

Cephalopoda

55. *Baculites* sp.

Gastropoda

58. *Architectonica* sp.
\+59. *Lunatia carolinensis* Conrad
\+60. *Seminola* sp. aff. *greenensis* Stephenson
\+63. *Solarium* sp.
64. *Turritella* sp.
65. *Volutodermata* sp.

Echinodermata

67. Spines
\+68. Plates
\+69. *Marsupites testudinarius* Springer

Brachiopoda

70. *Terebratulina guadalupe* Roemer

Table 7 contd.

Bryozoa
+72. Conopeum (aff. lacrioxii) Gray

Porifera
74. Cliona microturberum Stephenson

Annelida
75. Hamulus squamosus Gabb
76. Serpula pervermiformis Wade
77. Borings in shells

Coelenterata
+78. Microbacia hilgardi Stephenson

Shark Teeth
+79. Corax heterodon Reuss
+80. Lamna texana Roemer
+81. Otodus appendiculatus Agassiz
82. Oxyrhina mantelli Agassiz

Mammalia
+83. Trithecodon (?)

Trace Fossils
Thalassinoides
Oval cross-section
87. 1. straight

Note: + denotes species found only in this formation.

Diversity in the Pflugerville Formation is medium at the base and low near the top. The fauna of this formation is composed of 16 species, 12 of which are bivalve (Table 8). The richness is medium at the base, low in the middle, and medium at the top (see Appendix IV). In the lower half of the Pflugerville a large number of echinoid spines are found but no whole echinoids are present. The echinoid plates are disarticulated and scattered about separately, rather than clumped together as if the animal had been buried when it died. The

Table 8. Species found in the Pflugerville Formation.

Pelecypoda

1. Alectryonia falcata Morton
3. Anomia micronema Meek
5. Durania sp.
7. Exogyra ponderosa Roemer
9. E. sp.
12. Inoceramus sp. aff. grandis Conrad
15. I. sp.
16. I. sp., thick shell
22. Lima sp.
30. Ostrea centerensis Stephenson
31. O. congesta Conrad
32. O. plumosa Conrad
33. O. sp.
34. Pecten bensoni Kniker
+38. Pycnodonte sp. aff. convexa Say
39. P. sp.
45. Cucullea sp.

Gastropoda

+60. Lunatia (?) cretaceus Stephenson

Echinodermata

67. Spines

Bryozoa

71. Aplousina sp. aff. gigantea Conrad
+72. Laterotubigera (aff. cenomana) D'Orbigny

Annelida

75. Hamulus squamosus Gabb
76. Serpula pervermiformis Wade

Shark Teeth

82. Oxyrhina mantelli Agassiz

Trace Fossils

Thalassinoides
Oval cross-section
87. 1. straight
+93. Donut shaped (probably the stabilized area around the opening of a burrow).

Note: + denotes a species found only in this formation.

upper portion of the formation is covered by tall grass and was difficult to sample. The samples which were recovered were disarticulated, corroded, and sparsely distributed.

PALEOECOLOGY

General Environmental Data

In analyzing the depositional environment of the Austin Group in Travis County several sources of information were used. The most compelling data are the numerous disconformity surfaces found within the sequence. Two of these disconformities are present within the measured section; 1) at the base of the Dessau, and 2) at the base of the Burditt. The disconformity at the base of the Dessau is present at the Dessau type section. Two surfaces are present within the lower four feet of the Dessau. These surfaces are heavily burrowed and stained with pyrite. The disconformity surface at the base of the Burditt, at the Little Walnut Creek section, is burrowed and slightly stained. The lower Burditt contact is sharp, and the units above this contact are less resistant to weathering.

The lithologic evidence for depositional environments indicates that the Austin Group represents a fluctuation between high and low energy conditions. (Fig. 12) The coarse grained fragmental nature of the Jonah, Vinson, and McKnown Formations indicate high energy, shallow water conditions. In the chalk units thick and thin shelled animals were fragmented, very few shells were whole or articulated. The shells in the clays were not broken representing quiet water. The presence of two coquinoid beds in the Burditt Formation are interpreted likewise (Durham, 1957). The uniform depositional units within the Atco and upper Austin Formations indicate a prolonged period of quiet water deposition (Miller, 1978).

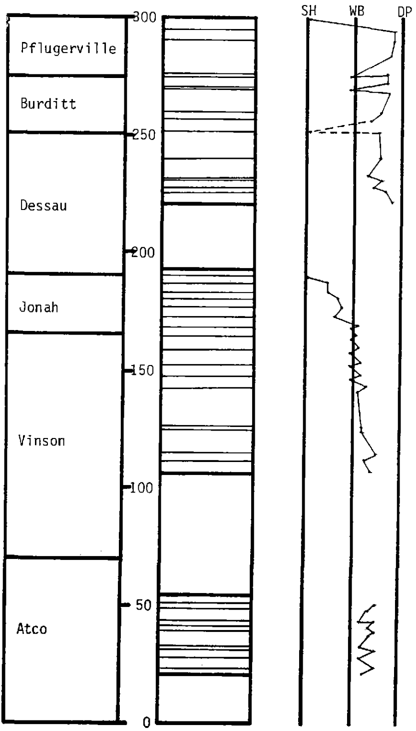

Figure 12. Relative water depths during deposition of the Austin Group in Travis County at the localities sampled. SH - shallower, WB - wave base, DP - deeper.

The faunal data also indicate shallow water deposition. The presence of the echinoderm Hemiaster texanus and the proliferation of spines and plates would indicate normal salinity and the great abundance of these would indicate shallow to moderate water depth (Dodd and Stanton, 1981).

The regional depositional setting supports the other information. During Austin deposition, central Texas was tectonically active (Miller, 1978). The San Marcos Arch (fig. 13) south of Travis County was a positive feature controlling deposition. The formations thin to the south as they lap up onto the arch. The rocks change in lithology from mudstone/wackestones to grainstones and packstones on the arch (Seewald, 1959). Another feature affecting deposition of the upper Austin Group in southeast Travis County was the formation of the Pilot Knob volcano. This volcano produced some localized relief and introduced a nearby source of clay and some pyroclastic (basaltine) materials to be incorporated into the formations. The McKnown facies of the Dessau Formation is the product of this activity. There may have been some volcanos or a landmass to the west to provide the abundant clay material found in the Burditt and Pflugerville Formations (Miller, 1978).

Paleoecology: Lower Austin

The Atco Formation represents shallow, quiet water deposition at a moderate distance from the clay source area. The presence of Inoceramus, whereas previously indicated, represents shallower water depths. The presence of deep burrowing also indicates relatively

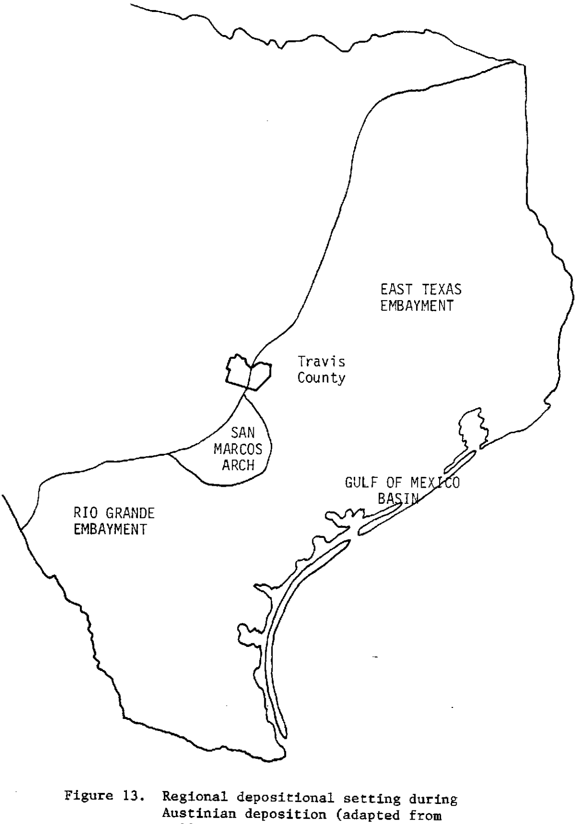

Figure 13. Regional depositional setting during Austinian deposition (adapted from Miller, 1978).

shallower water (Dodd and Stanton, 1981). The lack of sedimentary structures and whole, thin-shelled pelecypods indicates quiet water deposition (Miller, 1978). The rhythmic fluctuations from limy marl to marly limestone indicate a source area close enough to allow fluctuations of the amount of clays being brought out of the nearest landmass to affect deposition.

The Vinson Formation was deposited in a shallow water environment which, at times, was turbulent. The Vinson has a course grained texture and is composed predominantly of fragmented, thin-shelled bivalves. Most of the shells in this formation are fragmented, the results of abrasion and agitation in a high energy environment. Agitation also would winnow the clay particles out of the units. Slight deepening of the water resulted in the deposition of the thin clay seams. The clay seams also have fewer fragmented shells. The rhythmical alternation of these limestones and clays represent a fluctuating environment in relatively shallow water (Durham, 1957).

The Jonah Formation is similar in deposition to the Vinson with the exception of more frequent periods of quiet-water deposition. The Jonah Formation contains a high richness of organisms. The coarse texture is repeated in this formation indicating a continuation of shallow water, turbulent conditions. The clay layers are more frequent in this formation and represent shorter periods of agitation. The record of deposition of the Jonah, and the lower Austin Group, ends at the disconformity surface between the Jonah and Dessau Formations. This disconformity surface represents shallow water, possibly with some emergence (Durham, 1957).

Paleoecology: Upper Austin

The Dessau Formation was deposited in shallow water which, although it was initially agitated, in the upper portion was quieter water. The dual disconformity surfaces in the lower three feet of the Dessau represent a return to active, shallow water agitation. The associated clasts, burrowing, and coarse grained texture verify this trend (Durham, 1957). The upper Dessau has a homogeneous fine-grained texture and lacks sedimentary structures. This characteristic indicates shallow, quiet water deposition. In addition, the presence of many very large, whole-shelled *Inoceramus* support this interpretation of environment.

The Burditt Formation represents shallow, quiet water deposition interrupted by two periods of more turbulent conditions. A disconformity occurs below this portion of the Burditt. This surface is burrowed and was possibly a hardground area (Durham, 1957). The lower nine feet of the Burditt are chalk deposits. They have a low clay content and contain molds and whole shells. The molds indicate that most of the shells were disarticulated at the time of burial, but not fragmented. The middle and upper Burditt deposits consist predominantly of shaley chalk. These units contain *no* sedimentary strutures and a great abundance of echinoderm spines. This evidence would indicate relatively shallow, quiet water deposition (Dodd and Stanton, 1981). Two coquinoid beds in the upper Burditt contain fragmented shells and are coarser grained, probably deposited in shallower water. The clay content is higher in the upper Burditt Formation, possibly the result of uplift of areas to the west of the Balcones faulting. Another possible source would be an increase of volcanic activity related to the faulting.

The Pflugerville Formation represents a return to quiet water, uniform depositional conditions. The unit is not rich in fauna and has a high clay content. The lack of sedimentary structures would indicate quiet water (Miller, 1978). The lack of lithologic variation would indicate a cessation of the fluctuations present around the outcrop locations, influencing the deposition of the other formations of the upper Austin. The Pflugerville deposition terminates with the development of the disconformity surface and this would indicate a return to very shallow water, active conditions.

The foregoing interpretation of the depositional nature of the Austin Group in Travis County is consistent with the interpretation of Durham (1957), Seewald (1959), Miller (1978), and Dravis (1981). It is also consistent with the regional setting of deposition on the edge of the San Marcos Arch during a time of tectonic and volcanic activity. This fluctuation of the sea floor resulted in the differences in lithology and thickness that we find within the Austin Group.

BIOSTRATIGRAPHY

General Information

Biostratigraphy is the establishment of a subdivision of stratigraphic sections on the basis of faunal characteristics (Raup and Stanley, 1978). Several types of zones--1) assemblage zones, 2) biozones or occurrence zones, and 3) biohorizons--are used to subdivide the lithologic section. The assemblage zone is based on the occurrence of several species which typically are found together within a unit. The biozone is a subdivision of the section which extends from the first to last occurrence of a species. The biohorizon does not restrict a thickness of rock but indicates a time at which a particular organism first or last occurs. The assemblage zones and biozones restrict a package of rocks into a zone, the biohorizon indicates an event in time.

The complete range information for the fauna identified in this study is presented in Plate I and Plate II in the pocket. From the information compiled in these plates and the formation range charts in Appendix IV, zonation of the Austin Group for Travis County was prepared. Both biozones and biohorizons were established. For the biozonation the animals used were required to be 1) abundant, 2) easily located, and 3) in existence through a limited time span. To provide a viable zonation the species chosen fulfill these requirements as much as possible. For the establishment of biohorizons, the organisms used were required to be 1) abundant, and 2) not present in either the Eagle Ford or Taylor Group.

The zonations presented were established upon the basis of faunal data, but these are clearly affected by lithology. This was done to avoid zonation that would be influenced by fossils that have limited occurrences within a zone because of facies dependence (Valentine, 1971). The zones established are of a predominant lithologic type and the species chosen occur abundantly within both the zone and the lithology. This accommodation, while it solves one problem, may cause others.

Zonation

Five biozones were established for the Austin Group in Travis County. The five biozones are 1) Inoceramus subquadratus zone, 2) Pycnodonte wratheri - Pycnodonte aucella zone, 3) Trigonia aliformis zone, 4) Exogyra tigrina zone, and 5) Alectryonia falcata - Hamulus squamosus zone (fig. 14). The biozones are defined on the first and last appearance of the animals involved. The Pycnodonte wratheri - Pycnodonte aucella zone and the Alectryonia falcata - Hamulus squamosus zone are not based on co-occurrence of both animals but on the presence of either within the unit.

The lower Austin Group is divided into two zones. The Atco belongs in the Inoceramus subuadratus zone. This zone is equivalent to the I. subquadratus zone of Young and Marks (1952). The Jonah and Vinson Formations belong in the Pycnodonte wrateri - Pycnodonte aucella zone. Lithologically the Jonah and Vinson Formations are almost identical. The Texanites internodosus zone used by Young and Marks (1952) was based on an animal that was found only once in this

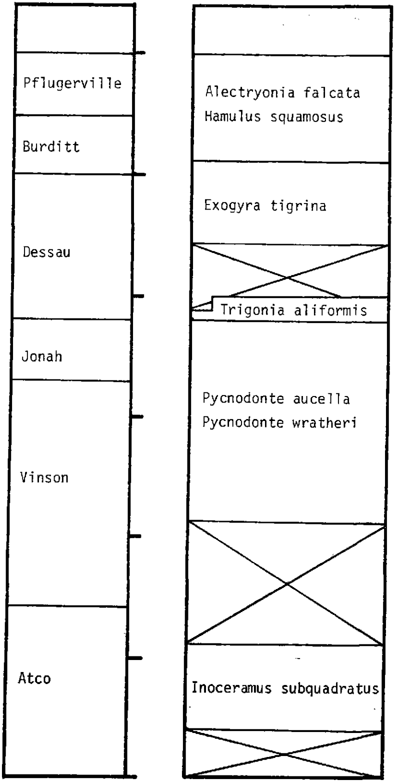

Figure 14. Biozonation of the Austin Group, Travis County, Texas (this paper).

study at the Vinson Creek outcrop. The fragmental, agitated nature of these formations destroyed most of the *Inoceramus* shells and the *Inoceramus undulatoplicatus* used by Stephenson (1937) was not found at all. The species could have been present at the time of deposition and destroyed by wave activity later.

The upper Austin Group is divided into three zones. The lowermost Dessau at the Vinson Creek location is in the *Trigonia aliformis* zone. As previously stated, *Exogyra ponderosa* also is discovered first in this section at that location but has a range too large to be used in detailed zonation. The exact upper boundary of this zone is unknown but no specimens of *Trigonia* were found in the upper Dessau present at Little Walnut Creek. *Trigonia aliformis* was not found at the Dessau type section but *E. ponderosa* was and the first appearance of *E. ponderosa* will mark the base of the "faunal Dessau Formation." The upper Dessau and the lower six feet of the Burditt fall into the *Exogyra tigrina* zone. This is essentially the same zone as the zone of the same name in Stephenson's (1937) zonation of the Austin.

The marls of the Burditt (six feet above the base and up) and the Pflugerville Formations fall into the final zone, *Alectryonia falcata - Hamulus squamosus*. These animals exist in extreme abundance and are easily identified. Stephenson's *Ostrea traviscana* is not present at the Little Walnut outcrop and Young and Marks did not actually observe rocks of the Pflugerville Formation in their outcrops in Williamson County.

Biohorizons

The biohorizon represents an event, such as the first or last appearance of a species within a section. Between closely spaced sections the biohorizons would represent the same period of time and correlation is possible. Table 9 lists the biohorizons which occur within the measured sections. These are presented to aid future studies of the Austin Group within Travis County. The horizons are related to formation contacts present in the measured sections.

The difference between biozones and biohorizons is important because of the way in which they are used. In the correlation of sections using biozones, the zones should not cross boundaries. These zones should represent sequential time, not facies or species migration. The biohorizon represents an event which may not have taken place at the same time at all locations. Correlation of these horizons does not correlate rock units as much as it correlates events.

Evaluation

In order to establish a biostratigraphic zonation, the relationship between the zone organism, lithology, and depositional environment must be considered. Generally, few benthic organisms are facies independent. Using benthic macrofauna for zonation has been proven to introduce facies dependence into the problem.

The *Inoceramus subquadratus* zone in Travis County is basically the equivalent of the same zone of Young and Marks (1952) in Williamson County. The extent of the lithologic component of this zone is important. The Atco Formation is uniform, alternating chalk and chalky marl. This uniformity of lithology is both vertical and horizontal. The lithology of the deposits of this zone are consistent

Table 9. Biohorizons within the Austin Group

Biohorizon	At
I. subquadratus (13)	Basal Atco
P. aucella (36)	60' below base Jonah
P. wratheri (37)	51' below base Jonah
B. asper (53)	41' below base Jonah
N. casteeli (27)	25' below base Jonah
B. anceps (51)	20' below base Jonah
N. hartmani (28)	15' below base Jonah
T. guadalupe (70)	11' above base Jonah
E. ponderosa (7)	Base Dessau
E. tigrina (8)	22' below base Burditt
E. laeviscula (6)	7' below base Burditt
A. falcata (1)	Base Burditt
L. crenulocostala (18)	6' above base Burditt
O. centerensis	12' above base Burditt
L. (aff. *cenomania*) (73)	Base Pflugerville
P. sp. aff. *convexa* (38)	12' above base Pflugerville

from Travis to McLennan Counties. Because of this lithologic uniformity, and the correlative zonations, this zone is probably useful over distances. For detailed stratigraphic work within the Atco Formation, there are no macrofauna to use.

The *Pycnodonte wratheri* and *Pycnodonte aucella* zone in Travis County, as found in the Vinson Creek section, is related to the lithology. The Vinson and Jonah Formations are predominantly bioclastic limestones. Most of the thin shells have been fragmented beyond identification. The zonation species must, as do the *Pycnodonte*, possess a thicker shell. Animals used for zonation in other areas, i.e. *I. undulatoplicatus*, may be present here but are fragmented. This zonation, if not facies dependent, is facies controlled.

The *Trigonia aliformis* zone is not found in northern Travis County but may be facies related to the shallow-water arch areas. The base of this zone is at the Jonah-Dessau disconformity. The appearance of *Exogyra ponderosa* which occurs as a biohorizon marker, will aid in delineating this zone in northern Travis County where the disconformity may be hidden. Of all the zones presented, this zone may be the most facies controlled.

In southern Travis County the upper Austin section is either 1) absent because of the effect of the Pilot Knob volcano, or 2) thinned because of the proximity to the San Marcos Arch platform. The zonations were established from data from the Little Walnut Creek locality.

The *Exogyra tigrina* zone in Travis County is roughly equivalent to Stephenson's (1937) zone of the same name. The lithology of this zone is marly chalk to chalk. The clay content is high at the base and decreases in the upper portion. The fact that this zone encompasses several lithologies and ends in the middle, not top, of a package of lithologically similar units may indicate that this zone is less facies dictated. If so, this may be the least facies dependent zone.

The Alectryonia falcata - Hamulus squamosus zone is based partially on abundance. The number of individual A. falcata may be equal to the number of individuals of all other species present in this zone. Ostrea traviscana, a very distinctive fossil which was used by both Stephenson and Young and Marks for the upper part of this zone, was not found at this outcrop. A. falcata and H. squamosus are present in both of the lithologies found within this zone. The environment was consistent for most of the deposition of this unit. Because of this consistency, the degree of facies dependence is not known.

Because of the unique relationship between organisms, their living environments, and the substrate characteristics, there may be almost no way to completely separate the fauna from facies controls. Zonation with benthic macrofauna without an established lithostratigraphic framework may mask or disguise migrational or facies effects and invalidate the results. Proper biozonation of a section of rock should include an analysis of the fauna, lithologic characteristics, faunal distribution, facies distribution, and the regional depositional framework. In the final analysis, the best biozone may not be the one which is the most correct, but the best zonation may be the one that works.

Comparison

A detailed comparison between the zonation presented in this study and those of Stephenson and Young and Marks is presented in the description of the zones. Figure 15 (p. 54) presents the relationship between these three zonations. A discussion about what the zones represent is just as important as comparing the sequences of those zones. The zonation presented in this study is a synthesis of lithologic, paleontologic, and regional setting information. The connection of the zonation with the stratigraphic section is important in aiding future studies of the Austin Group within Travis County.

Stephenson (1937) briefly studied outcrops over a wide area. Because of the broadness of his scope, fine detailed work was not possible. Without a stratigrahic framework to work from, Stephenson did not include the Atco Formation within the Austin section. Not only is the section incomplete but some of the zonation species do not exist in all outcrops of that age rocks. Stephenson's zones may represent biohorizons instead of biozones. They allow for the correlation of events, but not equivalent rock units.

Young and Marks (1952) established their zonations from a study of selected localities throughout Williamson County. The variations of the thickness of each unit and facies distribution are not mentioned. The zonation species, as presented, appear to exist in all rocks within its zone and are totally facies independent. If this were true, then the zonation should also work in Travis County, but it does not. Without an established stratigraphic framework from which to work, Young and Marks zoned a thickness of rock. Because litho-

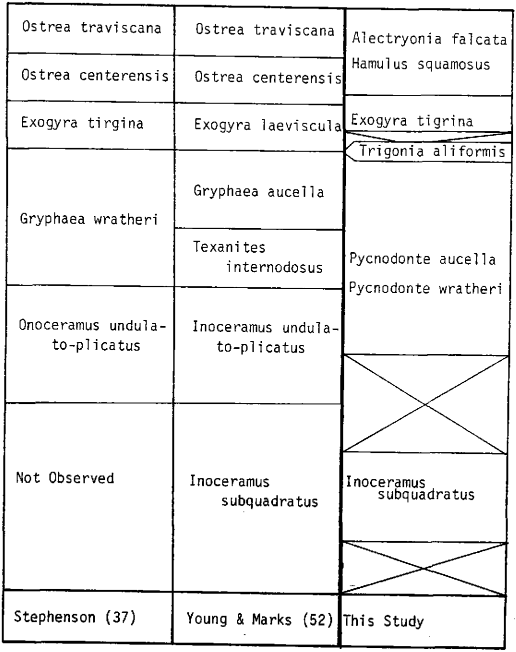

Figure 15. Comparison of the zonation in this paper with those of Stephenson (1937), and Young and Marks (1952). Correlations are approximate.

facies change with distance, rock to rock correlation is tenuous and comparison of zonations is difficult.

Stephenson and Young and Marks were not at fault when they established their zonations. Durham did not establish a stratigraphic framework until 1957. Both studies used the established methods of the time in which the studies were made. The present study is a product of today's methods that include a synthesis of lithologic, paleontologic, and regional setting information.

SYSTEMATIC IDENTIFICATION

Individual Identification

Pelecypoda:

1. Alectryonia falcata Morton (1827).
   Identified from Stephenson (1923, plate 39, fig. 1-10).
2. Anomia anomiaeformis Roemer (1849).
   Identified from Roemer (1852, plate 9, figs. 7 a-d) and verified from Roemer (1849).
3. Anomia micronema Meek (1876).
   Identified from Hill (1889, p. 7).
4. Astarte (?) lineolata Roemer (1852).
   Identified from Roemer (1852, plate 7, figs. 8 a-c).
5. Durania (Radiolites) austinensis Roemer (1852).
   Identified from Roemer (1852, plate 6, figs. 1 a-d).
6. Exogyra laeviscula Roemer (1849).
   Identified from Young and Marks (1952, plate 1, fig. 5) and verified from Roemer (1852, plate 9, figs. 3 a-c).
7. Exogyra ponderosa Roemer (1852).
   Identified from Young and Marks (1952, plate 1, fig. 6) and verified from Roemer (1852, plate 9, figs. 2 a-b).
8. Exogyra tigrina Stephenson (1916).
   Identified from Young and Marks (1952, plate 1, fig. 2).
10. Inoceramus sp. aff. cripsii Mantell (1833).
    Identified from Roemer (1852, plate 7, fig. 2).
11. Inoceramus grandis Conrad (1857).
    Identified from Udden (1907, p. 35-36).
13. Inoceramus subquadratus Schluter (1887).
    Identified from Adkins (1925, plate 34, fig. 6).
18. Lima crenulicostaa Roemer (1849).
    Identified from Roemer (1852, plte 8, figs. 8 a-c).
19. Lima reticulata Forbes (1845).
    Identified from Stephenson (1923, plate 53, figs. 10-15).
23. Linearia (?) cancellato-sculpta Roemer (1852).
    Identified from Roemer (1852, plate 6, fig. 10 a-b).
24. Liopistha sp. aff. elegantula Roemer (1852).
    Identified from Roemer (1852, plate 6, fig. 5 a-c).
25. Modiola sp. aff. granulato-cancellata Roemer (1852).
    Identified from Roemer (1852, plate 7, figs. 12 a-c).
26. Neithea austinensis Kniker (1919).
    Identified from Kniker (1919, plate 10, fig. 2).
27. Neithea casteeli Kniker (1919).
    Identified from Kniker (1919, plate 10, figs. 7-11).
28. Neithea hartmani Kniker (1919).
    Identified from Kniker (1919, plate 10, figs. 3-6, 12).
30. Ostrea centerensis Stephenson (1936).
    Identified from Shimer and Shrock (1944, plate 154, figs. 1-2).

31. *Ostrea congesta* Conrad (1843).
Identified from Shimer and Shrock (1944, plate 154, figs. 1-2).
32. *Ostrea plumosa* Morton (1833).
Identified from Stephenson (1923, plate 38, figs. 14017).
34. *Pecten bensoni* Kniker (1919).
Identified from Kniker (1919, plate 1, figs. 7-13).
36. *Pycnodonte aucella* Roemer (1852).
Identified from Young and Marks (1952, plate 1, fig. 8) and verified from Roemer (1852, plate 9, figs. 4 a-b).
37. *Pycnodonte wratheri* Stephenson (1936).
Identified from Stephenson (1936, plate 1, figs. 1-4).
38. *Pycnodonte* sp. aff. *convexa* Say (1820).
Identified from Shimer and Shrock (1944, plate 155, figs. 15-16).
40. *Spondylus guadalupe* Roemer (1852).
Identified from Roemer (1852, plate 8, fig. 9 a).
41. *Trigonia aliformis* Goldfuss.
Identified from Roemer (1849, p. 404).
44. *Cucullea* sp. aff. *millestriata* Shumard (1862).
Identified from Shumard (1862, p. 202).
48. *Neithea boesi* Kniker (1919).
Identified from Kniker (1919, plate 10, figs. 11-19).

Cephaolpoda:
51. *Baculites anceps* Lamark
Identified from Roemer (1852, plate 2, figs. 3 a-g).
53. *Baculites asper* Morton (1834).
Identified from Roemer (1852, plate 1, figs. 2 a-d) and verified from Morton (1834, plate 3, fig. 9).
55. *Texanites internodosus* Renz (1936).
Identified from Young and Marks (1952, plate 1, fig. 4).
57. *Texanites* sp. aff. *planatus* Lasswitz (1904).
Identified from Young (1963, plate 26, figs. 3-4).

Gastropods:
59. *Lunatia carolinensis* Conrad (1843).
Identified from Stephenson (1923, plate 88, figs. 17-19).
60. *Lunatia* (?) *cretaceus* Stephenson (1914.
62. *Seminola* sp. aff. *greenensis* Stephenson (1923).
Identified from Stephenson (1923, plate 93, figs. 10-11).
65. *Volutoderma* sp. Gabb (1861).
Identified from Stephenson (1923, plate 95, figs. 10-15).

Echinodermata:
66. *Hemiaster texanus* Roemer (1852).
Identified from Young and Marks (1952, plate 1, fig. 9) and verified from Roemer (1852, plate 10, figs. 4 a-c).
69. *Marsupites testudinarius* Springer (1911).
Single plate. Identification based on Marks (1950).

Brachiopoda:

70. Terebratulina guadalupe Roemer (1852).
    Identified from Roemer (1852, plate 6, figs. 3 a-d).

Bryozoa:

The bryozoans were identified from the Treatise of Invertebrate, Volume D.

Porifera:

74. Cliona microtuberum Stephenson (1941).
    Identified from Stephenson (1941, plate 3, figs. 1-5).

Annelida:

75. Hamulus squamosus Gabb (1861).
    Identified from Wade (1926, plate 2, figs. 8, 13).
76. Serpula pervermifermis Wade (1926).
    Identified from Shrock and Shimer (1944, plate 92, fig. 25).

Coelenterata:

78. Microbacia hilgardi Stephenson (?).

Shark Teeth:

All shark teeth identified from Roemer (1852, plate 1, figs. 6-9).

79. Corax heterodon Reuss (fig. 8).
80. Lamna texana Roemer (fig. 7).
81. Otodus appendiculatus Agassiz (fig. 9).
82. Oxychina mantelli Agassiz (fig. 6).
    81-82 verified from Agassiz (1843).

Mammalia:

83. Trithecodon. Identified by Dr. Lundelius, UT-Austin.

SUMMARY AND CONCLUSIONS

1. Complex normal faulting and antecedent faults produced in the Balcones Fault zone complicate the stratigraphic section by dissecting the outcrop sections and presenting only partial sections at any one locality.

2. The Austin Group is composed of alternating beds of limestone and marl. The limestone beds range from biogenic fragmental limestones as found in the Jonah and Vinson Formations to the marly limestones of the Burditt and Pflugerville. The marls have a high clay content and most are bioturbated to some extent.

3. The unconformities present at the base of the Atco, Dessau, and Burditt Formations and the unconformity surface at the top of the Pflugerville indicate that, at the time of deposition of the Austin Group, the water depth was shallow.

4. Molluscs dominate the fauna of the Austin Group and account for 70% of the species present. In most if the units the percentage of the mollusca in terms of the number of individuals is much greater. Of the molluscs present, the pelecypods are the most abundant with <u>Exogyra</u>, <u>Inoceramus</u>, <u>Pycnodonte</u> (<u>Gryphaea</u>), and <u>Neithea</u> being the dominant animal types.

5. The depositional setting of the Austin Group in Travis County is that of a shallow water epiric sea, probably near the slope into the Gulf of Mexico Basin. This relationship is evidenced by the compression of facies and the rapid thinning of the formations in the south. Deposition occurred near the wave base as indicated by the unconformity surfaces and the fragmental character of many of the

deposits. Overall deposition was in shallow water environments as evidenced by the fauna (i.e. Inoceramus).

6. Another factor influencing Austinian deposition was the Pilot Knob volcano. This volcano and its corresponding deposits appear slightly above the base of the Dessau. This area of positive relief changed facies conditions around it as evidenced by the wackestones found below the pyroclastic material and the grainstones and packstones found above. The pyroclastic material belongs to the McKnown facies of the Dessau. This elevation of bottom relief also caused the Burditt and Pflugerville not to be deposited in the area surrounding the volcanic neck.

7. Based on the data obtained from the collection of fossils from Travis County a basic zonation of the Austin Group has been made. These zones are based on the first and last occurrence of the animals involved.

a. Inoceramus subquadratus zone. This zone includes all of the Atco Formation and is the probable equivalent of the zone of the same name defined by Young and Marks(1952) in Williamson County to the North.

b. Pycnodonte aucella - Pycnodonte wratheri zone. This zone includes the rocks of the Jonah and Vinson Formations. Both of these units are lithologically similar and few complete samples of other zonation species used in other zonations were found. Whole specimens of the Pycnodonte are abundant at the outcrop.

c. Trigonia aliformis zone. This zone includes the lower portion of the Dessau Formation which is present at the Vinson Creek location. Exogyra ponderosa is also found to appear in this zone but extends into the Taylor Group and is therefore not useful in restrictive zonation.

d. Exogyra tigrina zone. This zone is composed of the upper portion of the Dessau Formation up to the Dessau - Burditt unconformity surface. E. tigrina appears in biostromal buildups scattered throughout this unit and may not occur in abundance at some localities.

e. Alectryonia falcata - Hamulus squamosus zone. This zone includes the rocks of the Burditt and Pflugerville formations and is based on the occurence of either of these species within the unit. The previously used zonation species do not occur in abundance, if at all, at the outcrops studied.

8. The zonation proposed by Stephenson (1937) was based on widespread regional studies and does not readily work in detailed unit study within Travis County. This zonation, made before a stratigraphic framework was constucted, relates to gross lithologic units over broad areas and is extremely difficult to relate to the framework devised by Durham (1957). The same restiction is true of Young and Marks (1952) zonation with the exception that their study was within a much smaller area.

9. Zonation in Travis County is hampered by the pronounced thinning and rapid facies changes over short distances along strike. This

situation is a result of the proximity of this area to the San Marcos Arch. The depositional environment in north Travis County is that of a moderate to shallow water shelf area (at least deeper than wave base). The depositional environment in south Travis County is in shallower water on the edge of the arch platform. As the facies change, so do the fauna. A zonation within one environment may not cross facies lines.

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APPENDIX I

Locality Description

Locality 1. MOPAC at West Oltorf Street

The outcrop is located between West Oltorf and Mary Streets along the creek bed below the Missouri Pacific Railroad tracks. This location is one-half block east of Lamar Boulevard and one-and-three-eighths mile south of the Colorado River. The outcrop is 2.5 miles southwest of the State Capitol. The section was measured from one-eighth mile downstream up to the MOPAC bridge. From there the section continues along the MOPAC tracks, along both sides, to Oltorf Street. The Atco is 34 feet thick at this location and is overlain by six feet of aluvium and soil.

Locality 2. Vinson Creek

The outcrop is located two hundred yards upstream of the Bluff Springs Road bridge on Vinson Creek. The outcrop is seven-eighths of a mile east of Interstate 35 and three-fourths mile north of the Onion Creek bridge of Bluff Springs Road. The outcrop is 6.6 miles south-southeast of the State Capitol. The section was measured on the west side of a prominent fault which cuts cross the outcrop. The section here is 84 feet tall and is composed of the upper 60 feet of the Vinson Formation, the Jonah Formation (24 feet thick), and the lower 1.5 feet of the Dessau Formation.

Locality 3. Little Walnut Creek

The outcrop is located three-eighths of a mile west of the intersection between Texas Highway 182 and Texas Highway 290 in northeast Travis County on Little Walnut Creek. The outcrop is above the right bank on the creek 300 feet upstream of the Texas Highway 290. The outcrop is 6.3 miles northeast of the State Capitol. The section was measured slightly downstream of a small creek which enters Little Walnut Creek and is 75 feet tall. Exposed at this outcrop is the upper 22 feet of the Dessau Formation, the Burditt Formation (25 feet thick), and the Pflugerville Formation (29 feet thick).

Locality 4. Dessau Type Section

The outcrop is located three-quarters of a mile downstream of the Dessau Road bridge over Walnut Creek on the left bank. The outcrop is across the stream from a utility substation and is 77 feet thick. This section is 8.1 miles northeast of the State Capitol. The section contains the entire Dessau Formation, 72 feet thick, with both the upper and lower contacts present.

Locality 5. McKinney Falls State Park

The section was measured at the lower falls of McKinney State Park. The Park is 6.3 miles southeast of the State Capitol and is located two miles due west of Pilot Knob Community. The section was measured from Onion Creek up to the parking area and is 46 feet thick. The McKnown, pyroclastic, facies of the Dessau Formation is exposed here. The lower six feet is altered basaltic material and the upper 40 feet is carbonate clastic limestone.

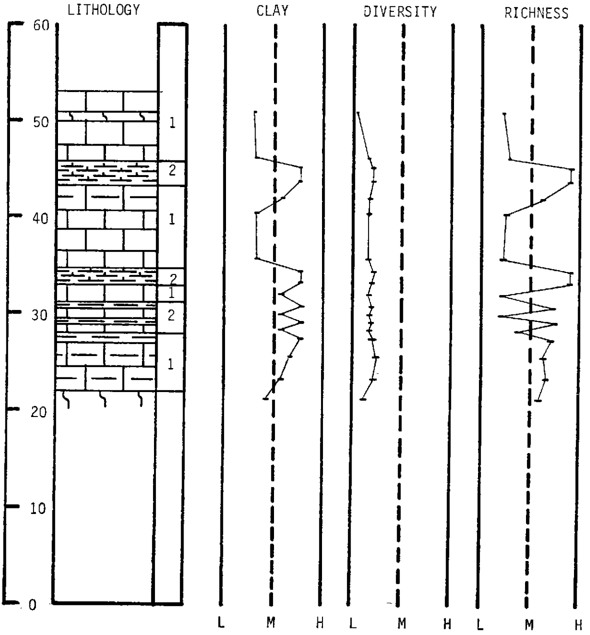
APPENDIX II

Lithology

Atco Formation

Lithology 1. (wackestone) Very light gray (N8) on weathered surface and white (N9) on fresh. The units have a fine grain texture with low clay content. The basal contacts are gradational. *Inoceramus* prisms and *I. subquadratus* are found throughout but few in number. Moderate burrowing is present and some pyrite is present throughout.

Lithology 2. (mudstone) Light gray (N7) on weathered surface and medium gray (N6) on fresh. The units have a fine grained texture and a high clay content. The basal contacts are gradational. Few *I. subquadratus* are found in the lower units. Intense burrowing is present throughout.



Lithologic Characteristics of the Atco Formation

Lithology

Vinson Creek Section

Unit A. Mudstone. Brownish gray (5yr4/7) on weathered surface and white (N9) on fresh. The unit has a fine grained texture. There is no basal contact observable and the portion of this unit which is visible is massively bedded. There is some pyrite present in this unit, especially as replacement for shell material.

Unit B. Mudstone. Light gray (N7) on weathered surface and very light gray (N8) on fresh. The unit is not as mottled as the previous and has a finer texture. This unit has less pyrite present. The basal contact is gradational against a clay lower portion. The unit is thin bedded and has a higher clay content than A.

Unit C1. Packstone. Yellowish gray (5Y8/9) on weathered surface and very, very light gray (N8.5) on fresh. The unit has a cream-white micrite matrix with thin, small bivalve fragments. The basal contact is gradational and the unit is thin bedded. This unit has some glauconite present. Pycnodone are abundant at the base with other animals being abundant at the top and base.

Unit C2. Mudstone. Light gray (N7) on weathered surface and light gray (N7) on fresh. The unit has a fine grain texture and is thin bedded. The unit is gradational with C1, with a higher clay content. There are few fossils present.

Unit C3. Wackestone. Medium gray (N6) on weathered surface and white (N9) on fresh. The unit has a fine grained texture with very small (0.5 mm) bivalve fragments. The basal contact is gradational. This unit has abundant glauconite present and also contains some finely dispersed pyrite.

Unit D. Mudstone. Yellowish gray (5Y8/1) on weathered surface and light gray (N7) on fresh. The unit is fine grained with few bivalve fragments. The basal contact is gradational. This unit has abundant glauconite and pyrite present.

Unit E. Wackestone. Pinkish gray (5YR8/1) on weathered surface and very light gray (N8) on fresh. The unit has a medium texture with bivalve fragments and few small gastropods. The basal contact is gradational. Glauconite is present in small amounts as is also sparry calcite.

Unit F. Wackestone. Medium light gray (N6) on weathered surface and very light gray (N8) on fresh. The unit has a medium texture with some Inoceramus prisms, whole bivalve shells, and a few gastropods. Most of the shells are fragmented. The basal contact is gradational. Glauconite is present throughout.

Unit G. Wackestone. Brownish gray (5YR7/1) on weathered surface and yellowish gray (5Y7) on fresh. The unit has a mottled texture with few possible intraclasts or burrows. The basal contact is gradational. Very little glauconite is present while pyrite is present in large pieces.

Unit H. Wackestone. Pinkish gray (5YR7/1) on weathered surface and very light gray (N8) on fresh. The unit has a highly mottled texture and contains abundant thin shelled bivalves. The basal contact is sharp. There is glauconite and pyrite throughout and the unit is highly bioturbated.

Unit I. Packstone. Yellowish gray (5YR8/1) on weathered surface and yellowish gray (5YR8/1) on fresh. The unit has a medium texture with Inoceramus prisms, thin shelled bivalves, and inflated gastropods present. The basal contact is gradational. The unit contains rich green glauconite, some pyrite, and abundant sparry calcite.

Unit J. Wackestone. Medium - dark gray (N6) on weathered surface and very light gray (N8) on fresh. The unit has a coarse grain texture with many fragments of Inoceramus and other thin shell bivalves. Some gastopods, few whole, are present. The basal contact is gradational. Some glauconite is present.

Unit K. Wackestone. Yellowish gray (5Y8/1) on weathered surface and very light gray (N8) on fresh. The unit has a coarse texture with many fragments of high spired gastropods and thin shell bivalves. The basal contact is gradational. A slight amount of finely dispersed glauconite is present.

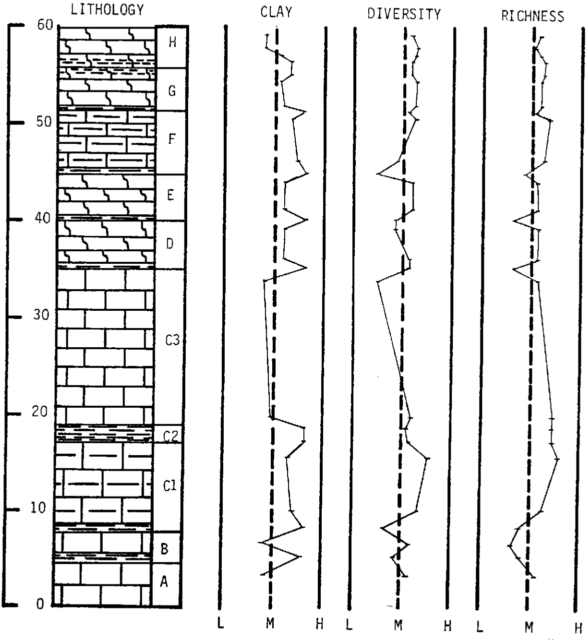
Unit L. Packstone. Yellowish gray (5Y8/1) on weathered surface and light yellowish gray (5Y8/1) on fresh. Original texture destroyed by diagenetic alteration leaving a mottled texture. This unit contains abundant sparry calcite and has a pyrite stain. The basal contact is gradational. Dark green glauconite throughout with some large, unaltered Inoceramus prisms.

Unit M. Wackestone. Pinkish gray (5YR8/1) on weathered surface and yellowish gray (5Y8/1) on fresh. Depositional texture obscurred by bioturbation resulting in a mottled, medium-coarse texture. The basal contact is gradational. Very small amounts of glauconite and pyrite are present. Particles include high-spired gastropods, fragmented thin-shelled bivalves, and slightly dissolved Inoceramus prisms.

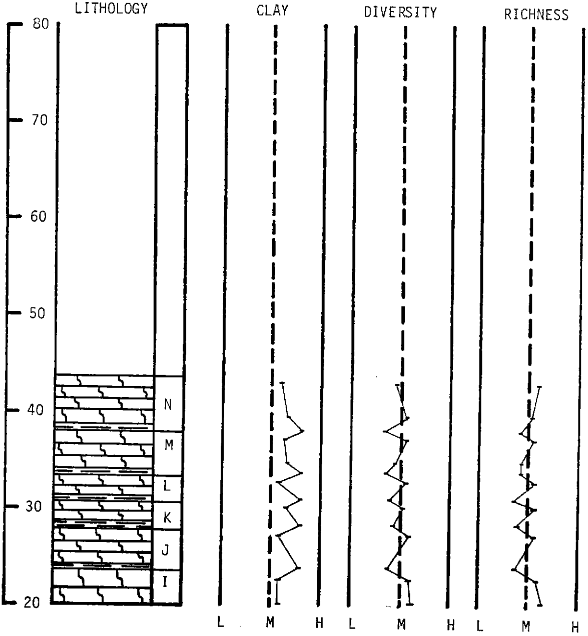
Unit N. Wackestone. Yellowish gray (5Y8/1) on weathered surface and very light gray (N8) on fresh. The texture is medium to fine with some bioturbation present giving a slightly mottled texture. The basal contact is gradational. Some glauconite and pyrite is present. All particles are very small (1 - 5 mm).

Unit O. Packstone. Yellowish gray (5Y8/1) on weathered surface and light yellowish gray (5Y8/1) on fresh. Original texture obscurred by diagenesis but was probably a very fine grainstone. The basal contact is irregular, sharp, and unconformable. Minor amounts of glauconite is present. The unit contains abundant limonite particles and stain. The other particles are small gastropods and very small fragments of bivalves.

NOTE: The colors conform to the Uniform Soil Survey Color Charts.



Lithologic Characteristics of the Vinson Formation



Lithologic Characteristics of the Jonah Formation

Lithology

Little Walnut Creek

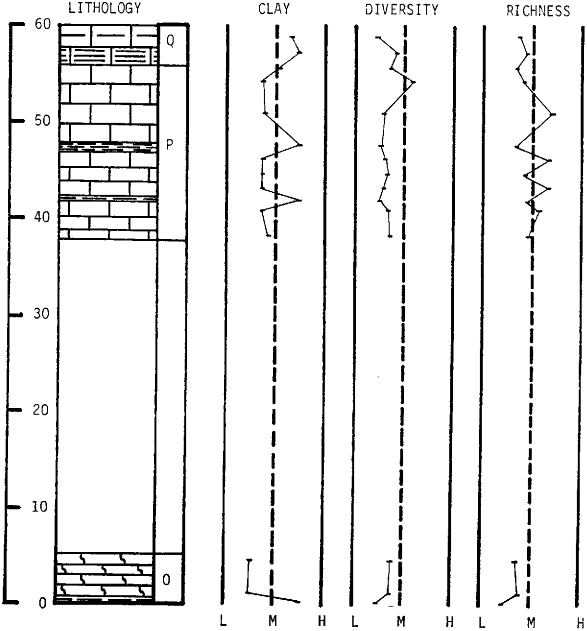
Unit P. Mudstone / Packstone. Medium light gray (N6) on weathered surface and very light gray (N8) on fresh. The unit has a fine grain, massive texture and an increasing clay content at the top. The basal contact is not observable. The Exogyra occur in banks and clusters within this unit. The Inoceramus achieve up to three feet in length.

Unit Q. Mudstone. Light gray (N/7) on weathered surface and very light gray (N8) on fresh. This unit has a fine grained, medium bedded texture. The clay content decreases at the top. The basal contact is gradational. Most of this unit is overgrown by tall grass.

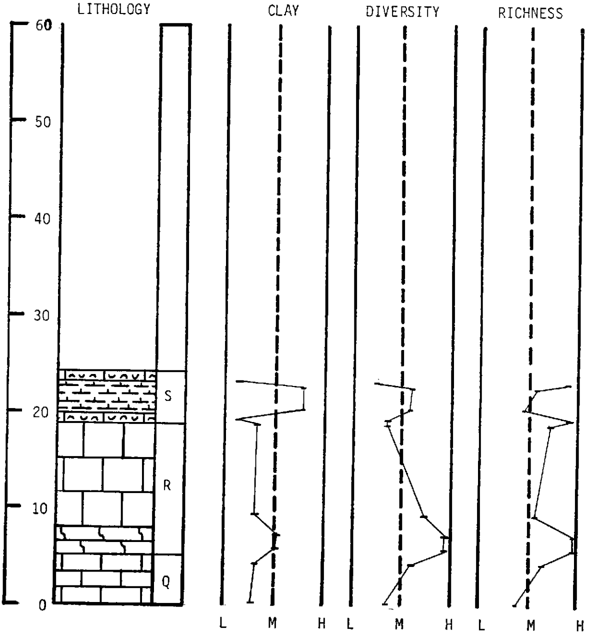
Unit R. Wackestone / Mudstone. Very light gray (N8) on weathered surface and light gray (N7) on fresh. This unit is a medium to fine grained unit with a nodular characteristic, more so at the base. The basal contact is gradational. The lower portion of this unit contains abundant bivalve and gastropod molds.

Unit S. Mudstone. Gray (N5) on weathered surface and medium light gray (N6) on fresh. The unit is fine grained and contains a high percentage (= 50%) clay content. The basal contacts are gradational.
Packstone. Yellowish gray (5Y8/1) on weathered surface and yellowing gray (5Y8/1) on fresh. These units, two of them, are coarse grained with fragments of Alectryonia falcata the prominent grain type (= 65%). The basal contacts are sharp.

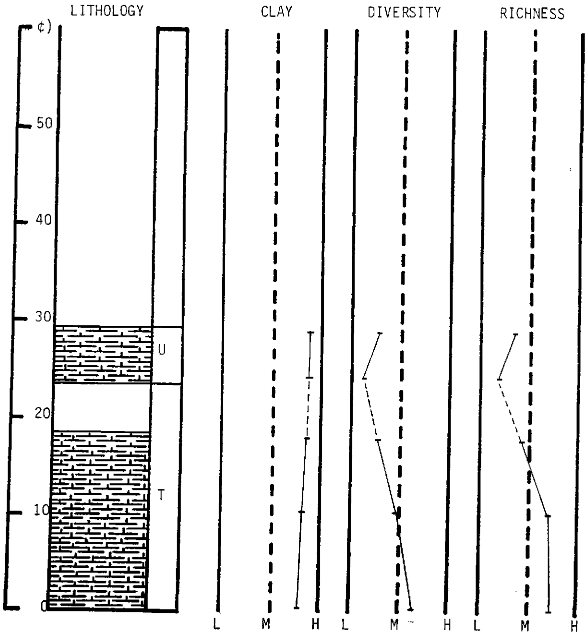
Unit T.
Unit U. These units are the same. They were divided for sampling of the faunal composition due to the dense overgrowth of grass and weeds in the upper unit.
Mudstone. Gray (N5) on weathered surface and medium light gray (N6) on fresh. This unit has a very fine grain texture. The basal contact is gradational. The unit turns gradationally to yellowish gray (5Y8/1) at the top and has a very high clay content.



Lithologic Characteristics of the Dessau Formation



Lithologic Characteristics of the Burditt Formation



Lithologic Characteristics of the Pflugerville Formation

APPENDIX III

Complete Faunal Listing

Pelecypoda

Alectryonia

1. Alectryonia falcata Morton (1833)

Anomia

2. Anomia anomiaeformis Roemer (1849)
3. Anomia micronema Meek (1876)

Astarte (?)

4. Astarte (?) lineolata Roemer (1852)

Durania

5. Durania austinensis Roemer (1852)
5. Durania sp.

Exogyra

6. Exogyra laeviscula Roemer (1849)
7. Exogyra ponderosa Roemer (1852)
8. Exogyra tigrina Stephenson (1916)
9. Exogyra sp.

Inoceramus

10. Inoceramus sp. aff. cripsii Mantell (1833)
11. Inocerramus grandis Conrad (1857)
12. Inoceramus sp. aff. grandis
13. Inoceramus subquadratus Schluter (1887)
14. Inoceramus sp. aff. subquadratus
15. Inoceramus sp.
16. Inoceramus sp., thick shell
17. Inoceramus sp., thin shell

Lima

18. Lima crenulicostata Roemer (1849)
19. Lima sp. aff. crenulicostata
20. Lima reticulata Forbes (1845)
21. Lima sp. aff. reticulta
22. Lima sp.

Lineraria (?)

23. Linearia (?) cancellata-sculpta Roemer (1852)

Liopistha

24. Liopistha sp. aff. elegantula Roemer (1849)

Modiola

25. Modiola sp.aff. granulato-cancellata Roemer (1852)

Neithea
26. Neithea austinensis Kniker (1919)
48. Neithea boesi Kniker (1919)
27. Neithea casteeli Kniker (1919)
28. Neithea hartmani Kniker (1919)
29. Neithea sp.

Ostrea
30. Ostrea centerensis Stephenson (1936)
31. Ostrea congesta Conrad (1843)
32. Ostrea plumosa Morton (1833)
33. Ostrea sp.

Pecten
34. Pecten bensoni Kniker (1919)
35. Pecten sp.

Pycnodonte (Gryphaea)
36. Pycnodonte aucella Roemer (1849)
37. Pycnodonte wratheri Stephenson (1936)
38. Pycnodonte sp. aff. convexa Say (1820)
39. Pycnodonte sp.

Spondylus
40. Spondylus guadalupe Roemer (1852)

Trigonia
41. Trigonia aliformis Goldfuss (in Giebel, 1853)
42. Trigonia sp. aff. aliformis
43. Trigonia sp.

Identification based on molds
44. Cucullea sp. aff. millestriata Schumard (1862)
45. Cucullea sp.
46. Lineria wp.
47. Volutomorpha sp.

Cephalopoda

Baculites
51. Baculites anceps Lamark (in Roemer, 1949)
52. Baculites sp. aff. anceps
53. Baculites asper Morton (1834)
54. Baculites sp. aff. asper
55. Baculites sp.

Texanites
56. Texanites internodosus Renz (1936)
57. Texanites sp. aff. planatus Lasswitz (1904)

Gastropoda

Architectonica

58. *Architectonica* sp.

Lunatia

59. *Lunatia carolinensis* Conrad (1843)
60. *Lunatia* (?) *cretaceus* Stephenson (1914)

Nereina

61. *Nereina* sp.

Seminola

62. *Seminola* sp. aff. *greenensis* Stephenson (1923)

Solarium

63. *Solarium* sp. Stephenson (1936)

Turritella

64. *Turritella* sp.

Volutodermata

65. *Volutodermata* sp. Gabb (1861)

Echinodermata

Hemiaster

66. *Hemiaster texanus* Roemer (1852)

67. Spines
68. Plates

Marsupites

69. *Marsupites testudinarius* Springer (1911)

Brachiopoda

Terebratulina

70. *Terebratulina guadalupe* Roemer (1852)

Bryozoa

Cheilostome

71. *Aplousina* sp. aff. *gigantea* Conrad (1857)
72. *Conopeum* (aff. *lacroixii*) Gray

Ctenostome

73. *Laterotubigera* (aff. *cenomana*) D'Orbigny

Porifera

Cliona

74. *Cliona microtuberum* Stephenson (1941)

Annelida

Hamulus

75. *Hamulus squamosus* Gabb (1861)

Serpula

76. *Serpula pervermiformis* Wade (1926)

77. Borings in shell

Coelenterata

Microbacia

78. *Macrobacia hilgardi* Stephenson (?)

Shark Teeth

Corax

79. *Corax heterodon* Reuss

Lamna

80. *Lamna texana* Roemer (1852)

Otodus

81. *Otodus appendiculatus* Agassiz (1843)

Oxyrhina

82. *Oxyrhina mantelli* Agassiz (1843)

Mammalia

Trithecodon

83. *Trithecodon* (sp?)

Trace Fossils

Thalassinoides

Circular cross-section

84. 1. straight
85. 2. tapering
86. 3. constriction

Oval cross-section

87. 1. straight
88. 2. arcuate
89. 3. intersection

Flattened cross-section

90. 1. straight
91. 2. tapered

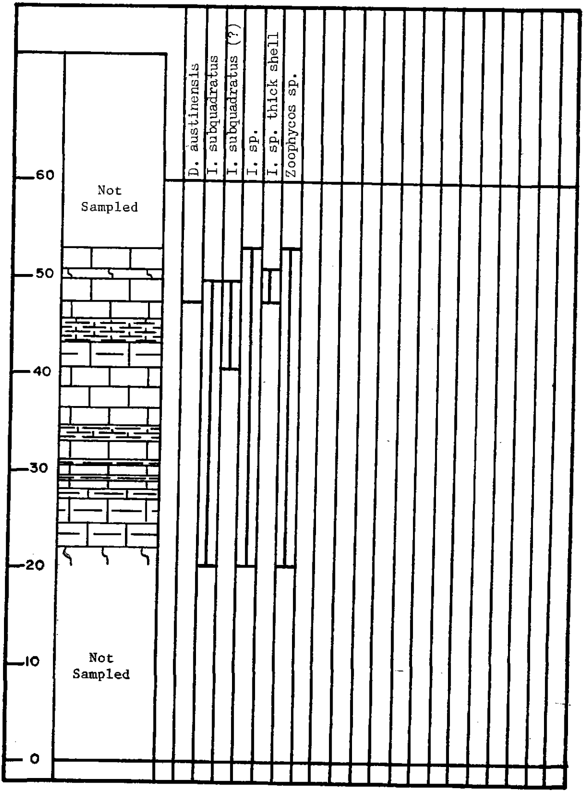
92. Nodulose

93. Donut shaped (probably the stabilized area around the opening of a burrow)

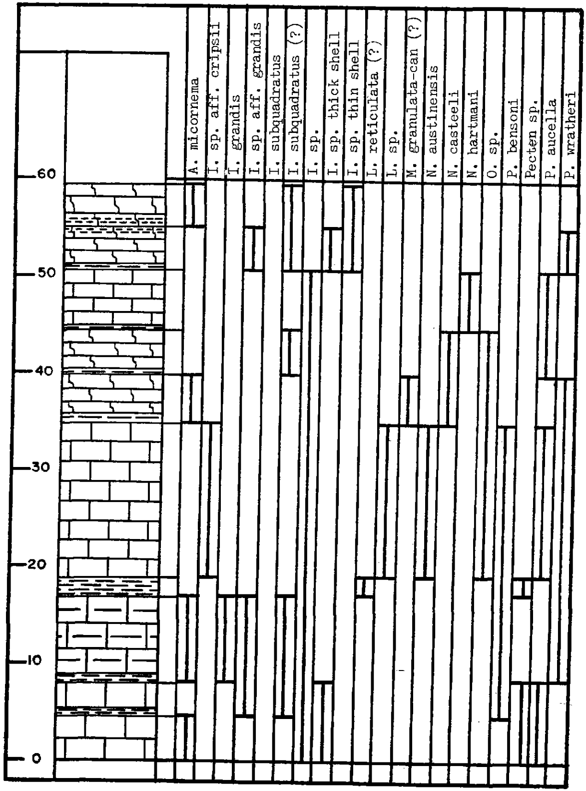
94. *Zoophycos* sp.

APPENDIX IV

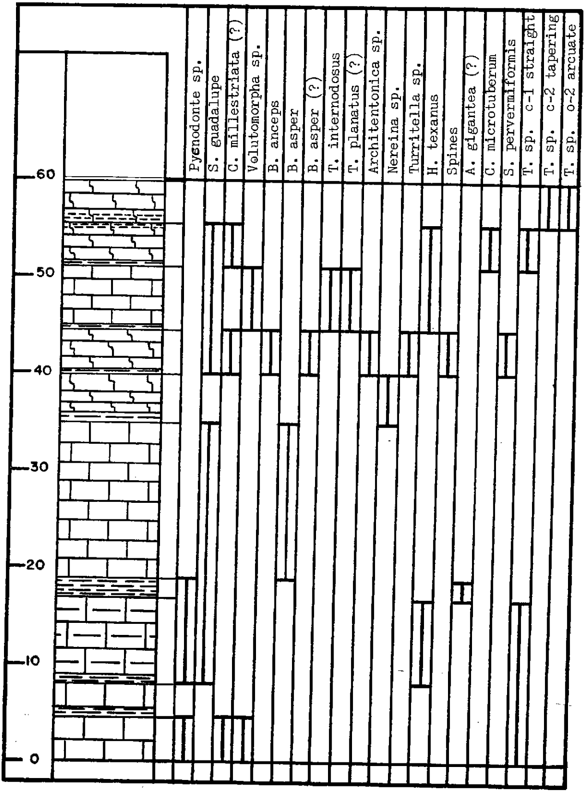
Formation Faunal Range Charts



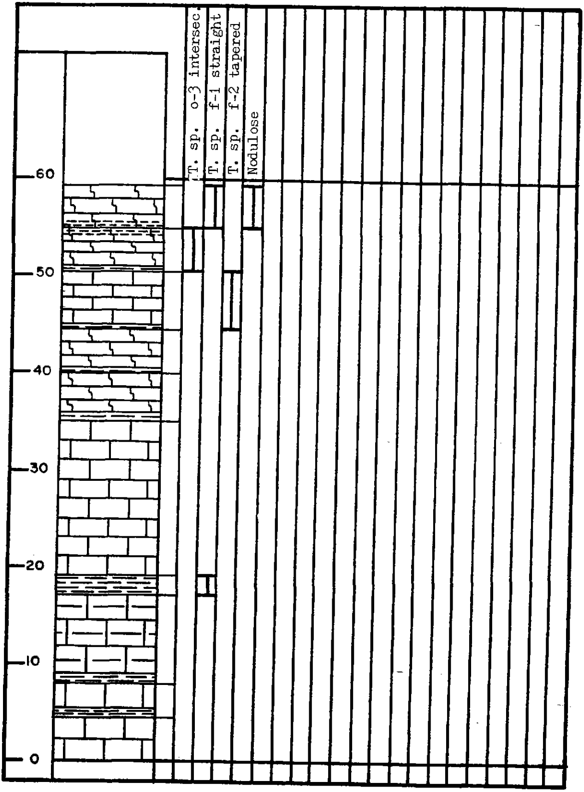
Faunal Range Chart for the Atco Formation



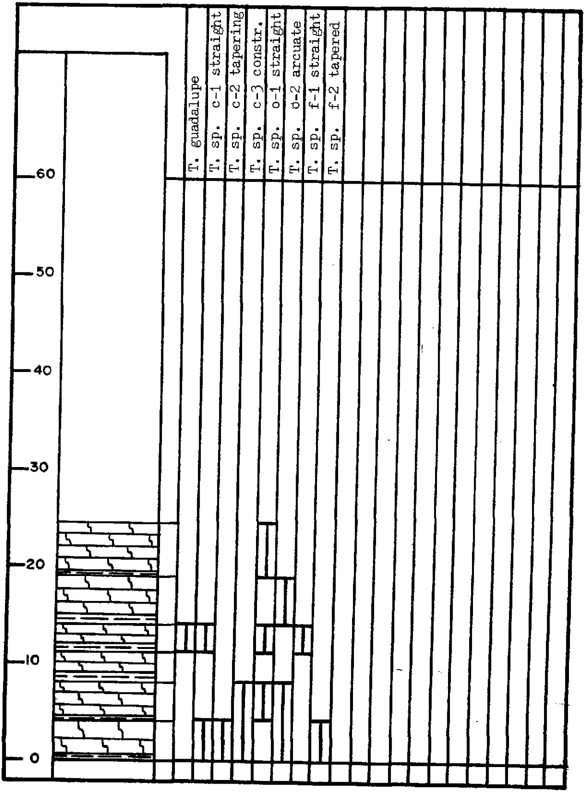
Faunal Range Chart for the Vinson Formation



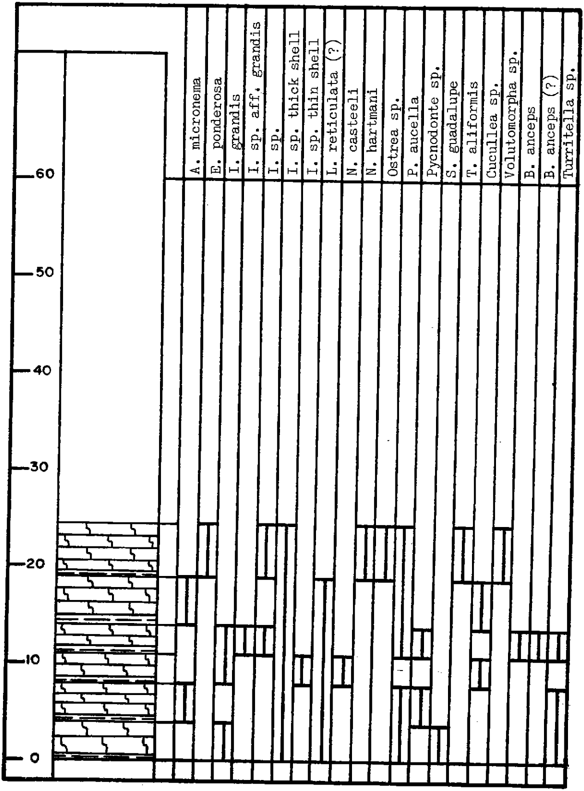
Vinson Formation (cont.)



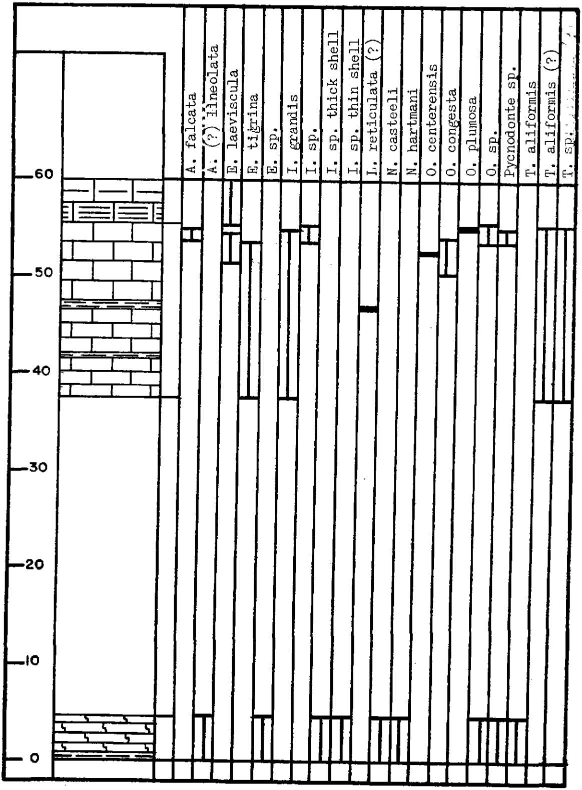
Vinson Formation (cont.)



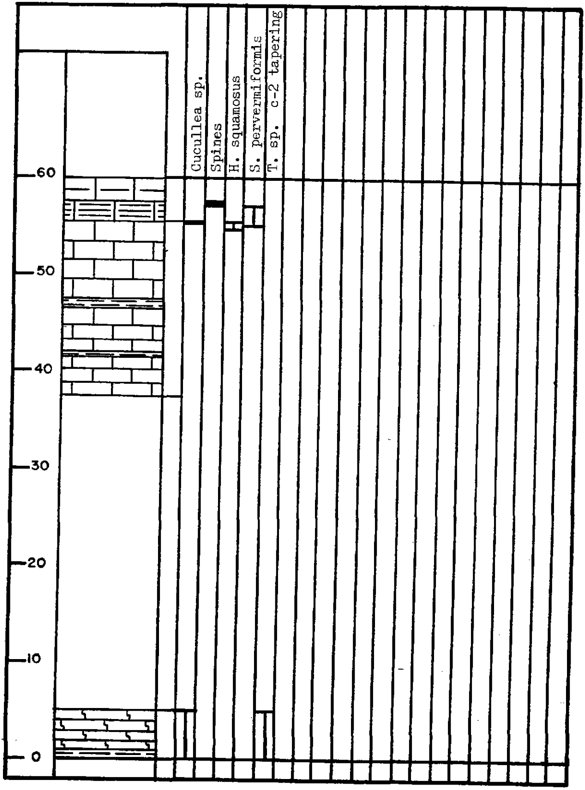
Faunal Range Chart for the Jonah Formation



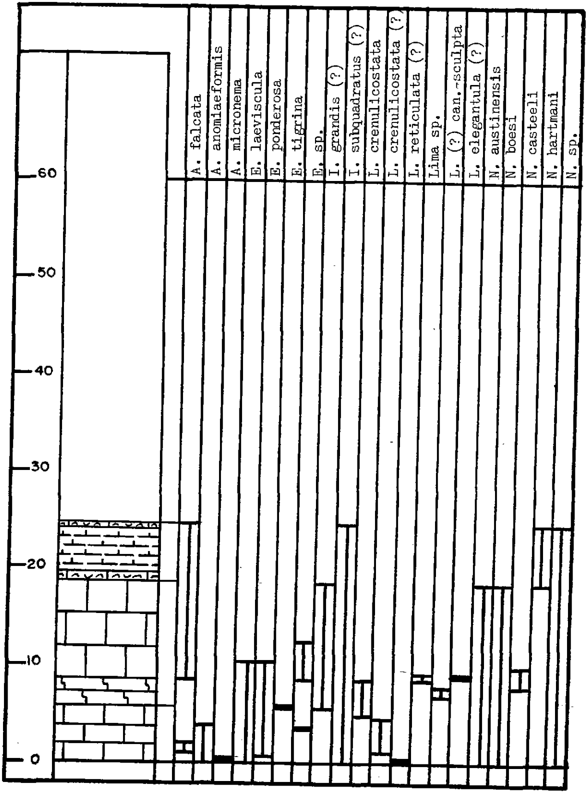
Jonah Formation (cont.)



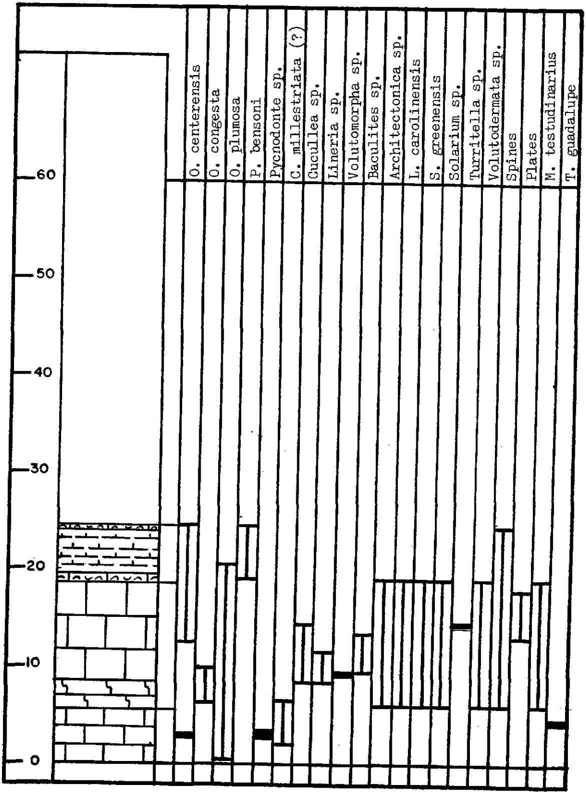
Faunal Range Chart for the Dessau Formation



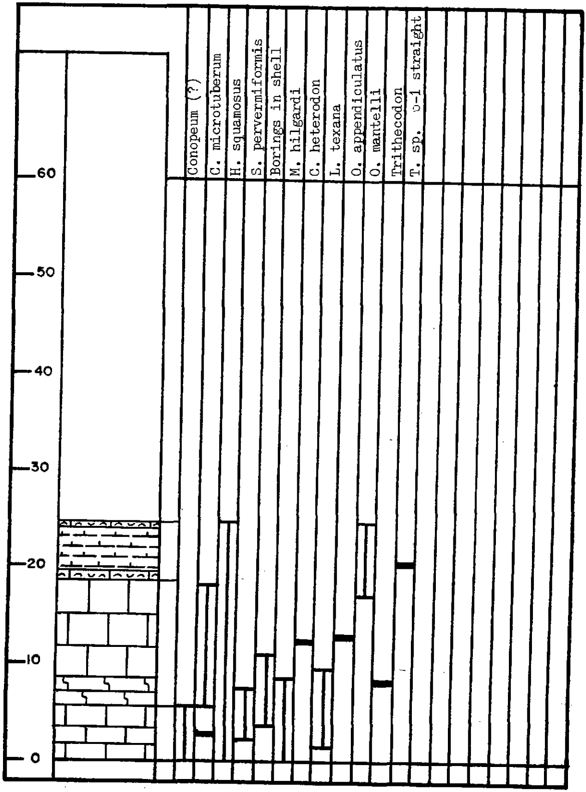
Dessau Formation (cont.)



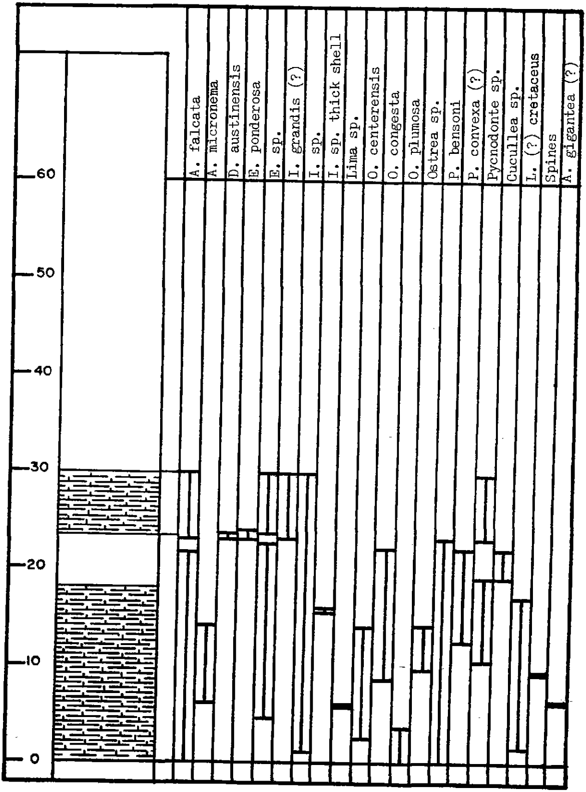
Faunal Range Chart for the Burditt Formation



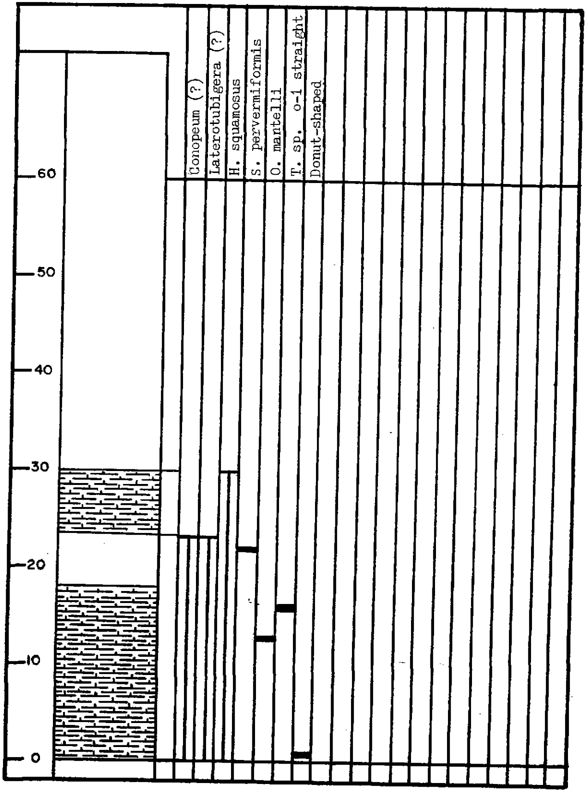
Burditt Formation (cont.)



Burditt Formation (cont.)



Faunal Range Chart for the Pflugerville Formation



Pflugerville Formation (cont.)

VITA

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